

Cooperation between Competitors -

Subcontracting and the influence of information, production
and capacity on market structure and competition

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Abstract

In this study we analyze the competitive effects of cooperation between competitors in the form of subcontracting and the influence of information, production and capacity on market structure and competition. Three game-theoretic models are developed to evaluate firms's strategies and the competitive effects of information sharing and production sharing. They are motivated by and applied to a case study of the flat glass market in order to evaluate the restrictive policy of the European Commission. The models analyze the effects of subcontracting and exchange agreements on information sharing, capacity decisions and production decisions. Welfare effects with and without subcontracting are then being compared. In a horizontal subcontracting model first signalling via subcontracting and secondly the effects on product variety and capacity decisions are being analyzed. In an exchange agreement model cooperation between competitors with different efficiency levels is being studied. The results show that technology and market characteristics determine whether subcontracting between competitors increases or decreases welfare. The market is able to develop mechanisms such as signalling via subcontracting to overcome inefficiencies but competition policy should stay attentive while allowing for a rule-of-reason.

Keywords:

competition, competition policy, European competition policy, information sharing, signalling, signaling, exchange agreement, production sharing, subcontracting, capacity, capacity sharing, glass market, flat glass market

Zusammenfassung

In dieser Arbeit wird eine wettbewerbspolitische Beurteilung der Zusammenarbeit von Wettbewerbern in Form von Querlieferungen vorgenommen und der Einfluß von Information, Produktion und Kapazität auf Marktstruktur und Wettbewerb analysiert. In drei spieltheoretischen Modellen werden die Unternehmensstrategien und die wettbewerblichen Effekte von Informationsaustausch und Produktionsaustausch untersucht. Sie wurden motiviert und werden angewandt auf eine Entscheidung zum Europäischen Flachglasmarkt, um die restriktive Wettbewerbspolitik der Europäischen Kommission zu beurteilen. Die Modelle untersuchen die Auswirkungen von Querlieferungen und Austauschvereinbarungen auf Informationsaustausch, Kapazitätsentscheidungen und Produktionsentscheidungen. Dabei wird die Wohlfahrt mit und ohne Querlieferungen verglichen. In einem Modell mit horizontalen Querlieferungen werden erstens Signalling via Querlieferungen und zweitens die Auswirkungen auf Produktvielfalt und Kapazitätsentscheidungen analysiert. In einem Modell mit Austauschvereinbarungen wird die Kooperation zwischen unterschiedlich effizienten Wettbewerbern untersucht. Die Ergebnisse zeigen, dass die Technologie und Marktcharakteristika festlegen, ob Querlieferungen zwischen Wettbewerbern die Wohlfahrt erhöht oder reduziert. Der Markt ist in der Lage, Mechanismen wie z.B. Signalling via Querlieferungen zu entwickeln, um Ineffizienzen zu mildern. Die Wettbewerbspolitik sollte aufmerksam bleiben, aber eine rule-of-reason zulassen.

Schlagwörter:

Wettbewerb, Wettbewerbspolitik, Europäische Wettbewerbspolitik, Austauschvereinbarung, Informationsaustausch, Signalling, Signaling, Querlieferung, Produktaustausch, Subcontracting, Kapazitätsentscheidungen, Glasmarkt, Flachglasmarkt

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Chapter 1

Introduction

During the last decades the nature of competition has changed. For firms the strategic interaction with competitors has become increasingly important and more complex. Now even cooperation with rival firms might be mutually beneficial. Cooperation can take place in a variety of forms. Two specific forms of cooperation, namely one-sided subcontracting in the form of *horizontal subcontracting* and two-sided subcontracting, termed *exchange agreement*, will be studied. In a horizontal subcontracting agreement one firm buys or sells production to or from a rival firm even though each firm could produce the product on its own. In an exchange agreement both firms buy and sell to each other by agreeing upon an exchange ratio.

Two economic aspects, which are the focus of antitrust concern, will be considered in detail: *information sharing* and *production sharing*. The competitive assessment of these forms of cooperation is an open question. While firms might achieve efficiency gains from more accurate information and by allocating production to the firm with lower production costs, the nature of competition changes as well. Competition policy has to assess the trade-off between efficiency gains and potentially collusive behaviour which might arise from better information or the division of markets through coordinated product variety and capacity decisions. This study aims to analyze firms' strategies and assess the *competitive effects* of cooperation between rival firms which take place in the form of subcontracting.

Methodologically, game-theoretic models are developed to derive general results. They were motivated by and are applied to a case study of the flat glass market in order to evaluate the restrictive policy of the European Commission towards these forms of cooperation expressed in decisions regarding

this industry.

The results show that technology and market characteristics determine whether subcontracting between competitors increases or decreases welfare. The horizontal subcontracting model will be used to analyze information sharing and production sharing, the exchange agreement model will focus on production sharing. With respect to *information sharing* the results are clear cut. First of all, it is possible to signal cost information via horizontal subcontracting. And in contrast to models of market information systems not only welfare and profits but also consumer surplus increases. If market information systems are forbidden the market develops the mechanism "signaling via subcontracting" in order to alleviate informational inefficiencies. Competition policy should take a favourable stand.

With respect to *production sharing* the results are more mixed. The antitrust fear is that of a division of markets established through the product variety offered and the capacities chosen by firms. Both types of subcontracting models will be considered.

First, a horizontal subcontracting model for the monopoly and the duopoly case focuses on the capacity and product decisions resulting from the dynamics of a growing demand. The results crucially depend on the relationship between the technologically given plant size and the level of demand. Both influence capacity utilization and thereby the willingness to subcontract and the welfare effects. The introductory monopoly case illustrates that a monopolist does not increase his capacity at the welfare optimal level of demand. Switching to higher capacity requires a higher than welfare optimal level of demand because the monopolist does not internalize the benefits from an increase in consumer surplus. In the duopoly case, product and capacity decisions change with subcontracting. Welfare might increase, in particular if capacity constraints are binding but it is not yet, due to high fixed costs, profitable for one firm to increase capacity on its own. Unfortunately, if firms are of symmetric size, either the firms or the consumers benefit but never both. So competition policy would either have to accept that welfare increases are split up unevenly or intervene. In the flat glass case this would warrant attention to the practice of a company subcontracting products.

Secondly, the exchange agreement model shows that if firms have different efficiency levels, that is marginal costs, then an exchange of products is beneficial for firms and Pareto dominant for society when compared to a situation without exchange agreement.

Both subcontracting models cover features of the flat glass market. In

a case of horizontal subcontracting, which the European Commission forbid, the objections were based on the fear of anti-competitive information sharing and production sharing. As the European Court reversed the European Commission's decision without explicitly deciding on these objections, the questions remain unresolved and the companies have grown hesitant to openly engage in subcontracting agreements. The exchange agreement model deals with a tacit practice in the industry.

Summarizing leads to the conclusion that the market is able to develop means to overcome inefficiencies on its own. Nevertheless, competition policy should be attentive when welfare but not necessarily consumer surplus increases. But rather than forbidding cooperation with a per-se rule anitrust authorities should allow for a rule-of-reason.

The questions pursued can be illustrated with the help of the market structure in figure 1. They have the common feature to focus on the influence of incomplete input markets on intermediate or final output markets with regard to competition and welfare.

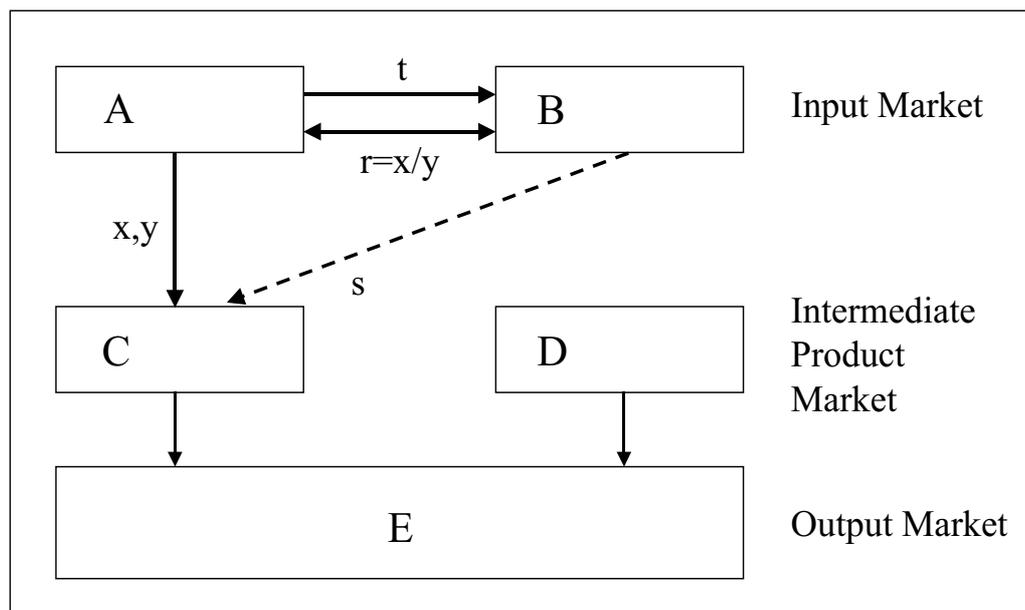


Figure 1.1: Market structure

Input markets are incomplete due to incomplete information or technology. For example, due to technology, only lumpy investments in capital-

intensive plants with high fixed costs and at given plant sizes might be possible. In addition, switching product lines on a given plant might incur additional fixed costs or increase marginal costs. Figure 1 shows a duopoly with two firms, A and B, which produce two products, x and y .

In a horizontal subcontracting model, firms operate at the same horizontal stage of the vertical supply chain of production and sell or buy a product from a rival firm, even though each firm is capable of producing the product independently. In figure 1, firm A unilaterally offers a transfer price t at which it is willing to subcontract (sell) the amount s of product x to firm B. Firm B then sells this quantity on the market of product x and competes directly against firm A.

In an exchange agreement model, firm A and firm B agree on an exchange ratio $r = x/y$ at which they bilaterally exchange quantities of the products. The focus of interest is on the way in which changes in the cost structures and more cost heterogeneity influence competition and welfare.

The study is organized as follows. References and reviews of the literature are dealt with in the respective chapters. Chapter II deals with the question of information sharing. Is it possible to signal information through subcontracting, and if this is the case, what welfare effects does this imply? Chapter III turns to the question of production sharing through subcontracting and introduces the monopoly model, where a monopolist faces capacity decisions with lumpy investments. Chapter IV extends the analysis of production sharing through subcontracting to a duopoly and determines the equilibrium capacity and product variety decisions. Chapter V turns to an exchange agreement model and determines the equilibrium exchange quantities. Finally, chapter VI contains a description of the flat glass market.

Chapter 2

Signaling through Subcontracting

2.1 Introduction

In a horizontal subcontracting agreement competing firms buy or sell production to or from a rival firm even though each firm could produce the product on its own. Two hypothesis have been advanced to explain this behaviour. On the one hand it is straightforward that firms can achieve efficiency gains if production is allocated to the firm with lower production costs. On the other hand this behaviour changes the nature of competition. This is the reason why antitrust authorities consider subcontracting as a potentially collusive device.

In Europe this is still an open question for competition policy. In particular, the European Commission has stated two fears. First, subcontracting might lead to specialization and a division of market. This is analyzed in the following chapters which focus on product variety and capacity decisions. Secondly, subcontracting is regarded as a means to collusively share information. The subcontracting price, at which one firm is willing to sell part of its production to a competitor, might be used to signal information in order to support collusion (see the flat glass case EC 1992 and European Court 1994).

The purpose of this chapter is to analyze if subcontracting can be used to signal information and, if this is the case, how signaling through subcontracting affects market behaviour and welfare. Subcontracting will be shown

to be a credible way to convey private information and influence a rival's beliefs and competitive behaviour. Signaling costs will have to be borne by the informed firm but they will not be socially wasteful because consumers benefit through lower prices. A discussion of the results will then be placed in the broader context of how informational settings influence competition and welfare. It is well known that in the presence of asymmetric information market equilibria often fail to be Pareto optimal. Nevertheless, the European Commission has been very critical of mechanisms such as information sharing and subcontracting which developed in the marketplace and which change the informational setting. Therefore, in order to reach policy conclusions, the different mechanisms will be compared. Signaling through subcontracting will be shown to be welfare enhancing and superior to information sharing through a market information system. Forbidding both mechanisms is the worst case scenario. Instead, inefficiencies due to informational asymmetry can be alleviated by a mechanism (subcontracting) which develops in the marketplace on its own. Subcontracting makes it possible to reach a constrained Pareto optimal allocation.

The signaling model focuses on the informational aspects of subcontracting in the presence of asymmetric information. In a duopoly, one firm has private information about its costs, which are either high or low. This informed firm sets a subcontracting price at which it is willing to sell the product to the uninformed firm. This price is observable and is a signal about the unobservable private cost. Then both firms compete in the same market. The uninformed firm has to decide how much to subcontract (buy) or produce on its own. The basic idea is that the informed firm will try to influence the uninformed firm's beliefs about its costs. The informed firm takes into account two countervailing effects when choosing the subcontracting price: an expectation and a subcontracting effect. On the one hand, the informed firm's profit increases if the other firm expects her to have low costs, i.e., a low-cost firm has an incentive to set a low subcontracting price in order to signal low costs. This can be a credible way of conveying information because the firm is committed to sell at this price and misleading signaling could be costly. A high-cost firm cannot profitably mimick every low-cost firm's price, because the subcontracting (selling) price might be below production costs and lead to losses. On the other hand, a low-cost firm is interested to subcontract (sell) the product at the highest possible price. As a result of this trade-off between the expectation and subcontracting effect, there will be either separating or pooling perfect Bayesian equilibria, depending on the

cost realizations. Separating as well as pooling equilibria only exist in a very small cost region, and here the refinement of the "intuitive criterion" is not able to help with equilibrium selection and elimination of the pooling equilibria. But in all other regions the refinement of Pareto dominance will lead to a unique separating equilibrium where firms noncollusively signal information and welfare and consumer surplus increases. Welfare in the signaling model will then be compared to welfare determined in the information sharing model. A comparison leads to policy conclusions whether to allow or forbid these mechanisms.

The related literature on information sharing focuses on the noncollusive incentives of firms to engage in information sharing. It analyzes the competition and, in part, the welfare effects of market information systems (see Li 1985 and Yin 1998 for further references). Nevertheless, the literature is not applicable because it always presumes that once all firms have decided to participate in a market information system, the information revealed at a later stage is truthful. This cannot be presumed with subcontracting: firms do not commit to a mechanism, e.g. a federation, which can verify the revealed information. Instead, one firm sets a subcontracting price at which it is willing to sell a product to the rival firm, but this price does not have to truthfully reflect the underlying cost or demand information. It can be used to influence the rival firm's beliefs and production decisions.

The literature on market signaling takes into account the strategic effects which arise in settings of asymmetric information (Mas-Colell, Whinston and Green, 1995). After Spence's seminal contribution of education as a signal, a wide range of applications followed, such as the classical articles on screening and signaling in insurance (Rothschild and Stiglitz, 1976), entry-deterrence (Milgrom and Roberts, 1982) and finance (Myers and Majluf, 1984). The informed firm is often interpreted as an incumbent and the uninformed firm as an entrant, with the entrant being uncertain about the cost of the incumbent. In this chapter, the signaling model is not one of entry-deterrence but of entry accommodation. The incumbent cannot deter entry, but only accommodate entry, that is the incumbent can only influence the production decision of the entrant (Chen, 1997). This is also a feature of the flat glass market. The informed firm can be viewed as facing different degrees of capacity utilization (leading to different opportunity costs), which are unobservable to the other firm. A different interpretation could emphasize the introduction of an innovation.

The basic articles in subcontracting have always assumed complete infor-

mation (Kamien, Li and Samet, 1989, and Spiegel, 1993). Only recently has incomplete information been introduced to models of subcontracting. These are models of vertical subcontracting, where a supplier tries to influence a manufacturer's beliefs about the supplier's costs. With vertical subcontracting, both firms could enter the market on their own, with outsourcing, one firm has lost this ability of entry (Van Mieghem, 1998). This chapter will consider a model of horizontal subcontracting, where both firms produce and compete at the same stage of the vertical supply chain and both firms can enter the market on their own.

The remainder of this chapter is organized as follows. In section (2.2) the signaling model is described and section (2.3) calculates the separating and the pooling equilibria. Section (2.4) contains a welfare comparison between the signaling model and a model with information sharing through trade associations. Section (2.5) concludes with a discussion of the results.

2.2 The model

In a signaling model, one firm has private information about its costs. The informed firm ("the incumbent") takes an action, here setting a subcontracting price. The uninformed firm observes the action, but not the private information. Yet the choice of the action is a signal about the informed firm's private information. (In a screening model the uninformed firm would take an action).

Consider two firms, 1 and 2, which compete in one market. Firm 1 can be of two types with high or low marginal costs $C \in (c_l, c_h)$ with $c_h \geq c_l \geq 0$. Firm 1's type will be called c_i ($i = l, h$). The prior probability of being a low cost type is $p_l = \Pr(C = c_l) \in (0, 1)$. Firm 1 has private information about its costs. They can be interpreted as representing firm 1's capacity utilization (opportunity costs) which is not observable by firm 2. In the model the private information concerns costs and not demand. Demand uncertainty is sometimes a feature in signaling models, but then it is less plausible to assume asymmetric information. Firm 2 does not know firm 1's type. The prior probability of firm 1 being a low-cost type, p_l , is common knowledge. It holds that $p_h = 1 - p_l$. Firm 2's constant marginal cost, c_2 , is common knowledge and normalized to $c_2 = 1$. There are no fixed costs of production.

Both firms can produce the homogeneous product x . Firm 1 is willing to subcontract (sell) the amount s of product x to firm 2. The inverse demand

function is linear with $P(x_1, x_2, s) = 2 - x_1 - x_2 - s$.

The signaling game is specified by the following sequence of rules, payoff functions and the solution concept. As to the rules of the game, nature first determines a cost realization for firm 1. Firm 1 has private information about its costs.

Stage 1: Firm 1 offers a subcontracting (transfer) unit price t , at which it is willing to sell product x to firm 2.

Stage 2: Firms compete in (Cournot) quantities. Firm 1 decides on its sale x_1 . Firm 2 simultaneously decides how much of its sale it wants to subcontract (buy) from firm 1, $s(t)$, and how much of its sale it wants to produce on its own, $x_2(t)$.

Formally, firm 1's type is c_i , $i = l, h$. Firm 1's action space in stage 1 is $T = \{t | t \geq 0\}$ and in stage 2 it is $X_1 = \{x_1 | x_1 \geq 0\}$. A strategy of firm 1, and I will only consider pure strategies, is a mapping from its type space to the Cartesian product of its action spaces, i.e. from $\{c_l, c_h\}$ to $T \times X_1$. Firm 2 cannot observe firm 1's type. However, it observes firm 1's action, the price offer t of stage 1, before deciding on her own action in stage 2. Firm 2's action space in stage 2 is $S \times X_2 = \{(s(t), x_2(t)) | s(t), x_2(t) \geq 0\}$. A strategy of firm 2 is a mapping from T to $S \times X_2$.

Firms' payoff functions are the expected profits.

The solution concept is that of a *perfect Bayesian equilibrium (PBE)*. It deals with the issues of updating and perfection in such a way that strategies and beliefs are mutually consistent in equilibrium.

In games of incomplete information, the concept of subgame perfection is extended by the idea of Bayesian updating in the following way. In the above game for example, at stage 2, firm 2 doesn't know firm 1's private information (firm 1's costs), so stage 2 is not a proper subgame. (Technically, the information set is not a singleton. The only subgame is the entire game.) But firm 2 observes firm 1's action before choosing her own action. Now in a Bayesian equilibrium firm 1's action can depend on its type. Therefore, firm 2 can observe firm 1's action (the subcontracting price) and update her beliefs about firm 1's type (low- or high-cost) before choosing her own action.

The perfect Bayesian equilibrium is a set of strategies and beliefs such that at any stage of the game, strategies are optimal given the beliefs, and the beliefs are obtained from equilibrium strategies and observed actions using Bayes' rule (Fudenberg and Tirole, 1992).

Updating is not possible if an action of firm 1 is not part of an optimal strategy and therefore a probability-0 event. Bayes' rule cannot be applied

to determine the posterior beliefs of firm 2 and any posterior beliefs are possible. This is the reason why a PBE doesn't restrict out-of-equilibrium beliefs and why there might be many equilibria. The refinements of *Pareto dominance* and the "*intuitive criterion*", which puts restrictions on the out-of-equilibrium beliefs, will be applied to determine a unique separating equilibrium (Mas-Colell, Whinston and Green, 1995 and Wolfstetter, 1998). This will be the equilibrium with the highest profit for the informed firm.

2.3 Signaling equilibria

A perfect Bayesian equilibrium cannot be determined by backward induction when there is incomplete information. Strategies are optimal given the beliefs and the beliefs are consistent with these optimal strategies. The argument is circular, so the equilibrium will be solved in two steps. *First*, for *given beliefs* the equilibrium strategies will be determined. *Secondly*, for these then *given equilibrium strategies* it will be checked which beliefs, and if in particular the beliefs used in the first step, are consistent with the equilibrium strategies. In equilibrium, beliefs and strategies have to be mutually consistent.

In a perfect Bayesian equilibrium two types of equilibria might arise. In a *separating* equilibrium the two types of firm 1 choose different actions, i.e., a low-cost type chooses a subcontracting price t_l and a high-cost firm chooses t_h , with $t_l \neq t_h$ (t_h might be a prohibitive price). In a *pooling* equilibrium the two types of firm 1 choose the same action, i.e. both types choose the same subcontracting price $t_l = t_h$. Firm 2 cannot infer information from observing the action to update its beliefs about firm 1's type.

2.3.1 Equilibrium strategies for given beliefs

At *stage 2*, firms' equilibrium strategies depend on the beliefs of firm 2 about firm 1's type. Firm 2's beliefs are a posterior distribution $\mu_i(t) = \mu(c_i | t)$ over firm 1's types ($i = l, h$). The belief functions $\mu_l(t)$ and $\mu_h(t) = 1 - \mu_l(t)$ denote the probability, with which firm 2 expects firm 1 to be a low-cost, respectively a high-cost type. These are the beliefs which will be assumed to be given. They will be discussed in more detail later.

At stage 2, firm 2 maximizes its expected profit after observing the subcontracting price t

$$\max_{s, x_2} E\pi_2(t) = (2 - x_1^e - x_2 - s)(x_2 + s) - c_2 x_2 - ts \quad (2.1)$$

with x_1^e being firm 1's expected sale. The beliefs are important for determining x_1^e . It holds that $x_1^e(t) = \mu_l(t) x_1(c_l, t) + \mu_h(t) x_1(c_h, t)$ with $x_1(c_i, t)$ denoting firm 1's sale when firm 1's type is c_i , $i = l, h$ (In the linear case this is equivalent to $x_1^e(t) = x_1(c^e, t)$ with $c^e = \mu_l(t)c_l + \mu_h(t)c_h$).

Firm 2's total sale on the market, $X_2 = s + x_2$, is the sum of the quantity subcontracted (bought) from firm 1, s , and the quantity produced by firm 2 on its own, x_2 . The marginal costs determine how much to subcontract (buy) and how much to produce. If the subcontracting price t is (weakly) less than the marginal cost c_2 ($c_2 = 1$), then firm 2 will subcontract all of its sale, otherwise, if $t > 1$, firm 2 will produce all of its sale on its own. In all of the following piecewise defined functions it is useful to keep in mind, that only for $t \leq 1$ subcontracting will actually occur.

Formally, derivation of firm 2's profit in equation (2.1) yields that

$$\frac{d\pi}{ds} \begin{matrix} > \\ < \end{matrix} \frac{d\pi}{dx_2} \quad \text{if } \begin{matrix} t < 1 \\ t > 1 \end{matrix}$$

So either firm 2 subcontracts or produces all of its sale. Firm 2's reaction functions are

$$(s(t), x_2(t)) = \begin{cases} (\frac{2-t-x_1^e}{2}, 0) & \text{if } t \leq 1 \\ (0, \frac{1-x_1^e}{2}) & \text{if } t > 1 \end{cases}$$

At stage 2, firm 1 maximizes its expected profit, depending on its type c_i , $i = l, h$ and the subcontracting price t

$$\max_{x_1(c_i, t)} \pi_1(c_i, t) = (2 - x_1 - x_2^e - s^e)x_1 - c_i x_1 + (t - c_i)s^e \quad (2.2)$$

Note that the expected profit of firm 2 refers to the random variable c_i while the profit of firm 1 refers to x_2^e and s^e as firm 1 knows its cost c_i with certainty. Then firm 1's reaction function is

$$x_1(c_i, t) = \begin{cases} \frac{2-c_i-s^e}{2} & \text{if } t \leq 1 \\ \frac{2-c_i-x_2^e}{2} & \text{if } t > 1 \end{cases}$$

In equilibrium, the expected output is equal to the actual output, that is $x_1^e(c_i, t) = x_1(c_i, t)$, $x_2^e(t) = x_2(t)$ and $s^e(t) = s(t)$ for $i = l, h$. Solving yields the equilibrium quantities.

Proposition 1 *The equilibrium sales at stage 2 are*

$$x_1^*(c_i, t) = \begin{cases} \frac{4-c^e-3c_i+2t}{6} & \text{if } t \leq 1 \\ \frac{6-c^e-3c_i}{6} & \text{if } t > 1 \end{cases} \quad (2.3)$$

$$(s^*(t), x_2^*(t)) = \begin{cases} (\frac{2+c^e-2t}{3}, 0) & \text{if } t \leq 1 \\ (0, \frac{c^e}{3}) & \text{if } t > 1 \end{cases} \quad (2.4)$$

Proof. See above. ■

Note that the employed beliefs of firm 2 about firm 1's type have upto now only been specified as general belief functions $\mu_l(t)$ and $\mu_h(t)$. They determine expected sales and costs, e.g. $c^e = \mu_l(t)c_l + \mu_h(t)c_h$.

The subcontracting price t influences the optimal quantities through a subcontracting and an expectation effect. If the subcontracting price t increases up to $t = 1$, firm 2's marginal costs increase and the optimal quantity $s^*(t)$ decreases. Firm 1's optimal output $x_1^*(c_i, t)$ increases. If the expectation about firm 1's cost $c^e(t)$ decreases then firm 1 increases and firm 2 decreases its optimal output, because firm 1 is expected to follow a more aggressive strategy.

At *stage 1*, firm 1 maximizes its expected profit

$$\max_t E\pi_1(c_i, t, c^e(t)) = (2 - x_1 - x_2^e - s^e)x_1 - c_i x_1 + (t - c_i)s^e \quad (2.5)$$

The terminology will be as follows. The first term, c_i , is firm 1's true type, the second term is the subcontracting price t and the third term $c^e(t)$ is firm 2's expectation about firm 1's type (e.g., in a separating equilibrium beliefs will be such that the expected type will always be firm 1's true type, that is $c^e(t) = c_i$). Inserting the equilibrium sales of stage 2 given in proposition (1) into the profit function in equation (2.5) leads to the reduced form profit function.

Proposition 2 *The equilibrium profits at stage 1 are*

$$E\pi_1(c_i, t, c^e(t)) = \begin{cases} \frac{16-8c^e+(c^e)^2-48c_i-6c^e c_i+9c_i^2+40t+8c^e t+12c_i t-20t^2}{36} & \text{if } t \leq 1 \\ \frac{(6-c^e-3c_i)^2}{36} & \text{if } t > 1 \end{cases} \quad (2.6)$$

Proof. See above. ■

Firm 1 now decides on a subcontracting price t . In equilibrium two self-selection conditions have to be met. The low-cost and the high-cost type firm choose actions t_l and t_h which lead to the highest expected profits. The conditions become intuitively clear when explained in the context of the separating or pooling equilibrium. For completeness they will be stated in their general form here as well

$$\pi_1(c_h, t_h, c^e(t_h)) \geq \pi_1(c_h, t, c^e(t)) \quad (2.7)$$

$$\pi_1(c_l, t_l, c^e(t_l)) \geq \pi_1(c_l, t, c^e(t)) \quad (2.8)$$

for all t . In a separating equilibrium the actions t_l and t_h will be different, in a pooling equilibrium, if one exists, they will coincide.

2.3.2 Equilibrium beliefs for given strategies

In a PBE beliefs have to be consistent with the equilibrium strategies. Two types of equilibria, each with different equilibrium strategies, are possible.

In a separating equilibrium, each type chooses a different action. A low-cost type chooses a subcontracting price t_l and a high-cost firm chooses t_h with $t_l \neq t_h$. In equilibrium the choice of t is a perfect signal about the private information of firm 1. The beliefs will typically be altered radically after observing t . The belief function $\mu_l(t)$ determines how the a priori belief p_l , that firm 1 is a low-cost type, is updated after observing t to the posteriori belief $\mu_l(t)$ that firm 1 is a low-cost type. In a separating equilibrium, beliefs are such that

$$\begin{aligned} \mu_l(t_l) &= 1 \\ \mu_l(t_h) &= 0 \end{aligned}$$

respectively $c^e(t_l) = \mu_l(t_l)c_l + \mu_h(t_l)c_h = c_l$ and $c^e(t_h) = c_h$. An offer t is a perfect signal. After observing the offer, firm 2 knows firm 1's type with certainty.

In a pooling equilibrium the two types of firm 1 choose the same action ($t_l = t_h$), so the equilibrium strategies are very different from those of a separating equilibrium. The belief functions are different as well

$$\mu_l(t_l) = \mu_l(t_h) = p_l$$

respectively $c^e(t_l) = c^e(t_h) = c^e$ with $c^e = p_l c_l + p_h c_h$. Observing price t doesn't change the a priori beliefs.

For both equilibria, observing an action off the equilibrium path is an event with probability zero. Updating is not possible and there are no restrictions on the belief functions. Any out-of-equilibrium beliefs are possible.

2.3.3 Separating equilibria

The above results will simplify the calculation of a separating equilibrium. The two *self-selection* conditions of equation (2.7) and (2.8) will be crucial. They ensure that the signal is *credible*. No firm has an incentive to misrepresent its type. In a separating equilibrium the self-selection equilibrium conditions are

$$\pi_1(c_h, t_h, c_h) \geq \pi_1(c_h, t, c_l) \quad (2.9)$$

$$\pi_1(c_l, t_l, c_l) \geq \pi_1(c_l, t, c_h) \quad (2.10)$$

for all t .

The interpretation is as follows. Equation (2.9) states that a high-cost firm has no incentive to mimic a low-cost firm. In profit $\pi_1(c_h, t_h, c_h)$, firm 1's true type is c_h , the offered subcontracting price is t_h and firm 2's beliefs about firm 1's type have been updated to the true type, c_h . In the deviation profit $\pi_1(c_h, t, c_l)$, firm 1 has high-costs c_h , it could nevertheless signal low-cost via t and mislead firm 2 to believe that it has low-costs c_l . The equation states that signaling the true type is more profitable than misrepresenting the type. This can be explained as follows. A high-cost firm 1 would want to mislead the uninformed firm 2 and mimic a low-cost firm's type. If a high-cost firm 1 could successfully signal low-costs, firm 2 would produce less and firm 1's profit would increase. On the other hand, the high-cost firm 1 would have to subcontract (sell) the product possibly below its own marginal costs. So a high-cost firm 1 cannot mimic every low-cost firm's price. In a separating equilibrium, firm 1 will never mislead firm 2, firm 1 will always signal its true type.

Equation (2.10) states in a similar way that the low-cost type has no incentive to signal being a high-cost type.

The two self-selection conditions hold if it is more expensive for a high-cost type to signal low costs than it is for a low-cost type. This assumption is

known as the single-crossing property (Kreps, 1990). In the subcontracting model it almost always holds that signaling is cheaper for the low-cost type, so that he can successfully distinguish himself from the high-cost type.

Solving both equations and applying the refinement of Pareto dominance yields the unique separating equilibrium.

Proposition 3 (*Unique separating equilibrium*). *The following beliefs and strategies are a separating equilibrium. It is the unique separating equilibrium with respect to Pareto dominance.*

$$\mu_l(t) = \begin{cases} 1 & \text{if } t \leq t^* \\ 0 & \text{if } t > t^* \end{cases} \quad (\text{equilibrium beliefs})$$

$$(t_l^*, t_h^*) = \begin{cases} (t_{\max 2}, -) & \text{if region Ib} \\ (1, -) & \text{if region IIa} \\ (1, -) & \text{if region IIb} \\ \text{no offer} & \text{if otherwise} \end{cases} \quad (\text{equilibrium prices})$$

with $t^* = t_l^*$ and with terminology $t_h^* = "-"$ if $t_h^* > 1$ (i.e. any price at which no subcontracting occurs). The value $t_{\max 2}$, which is less than 1, and the regions are defined in equations (A.9) and (A.15) in appendix (A.1). The regions are illustrated in figure (2.1). Firms' equilibrium sales are determined according to proposition (1).

Proof. The proof of being a *separating equilibrium* consists of two parts. First, take the beliefs as given. Then for every type, deviation from the equilibrium strategies is not profitable, i.e. the self-selection conditions $\pi_1(c_i, t_i^*, c_i) \geq \pi_1(c_i, t, c^e(t))$ ($i = l, h$) have to hold for all t . The subcontracting price t_i^* is firm 1's best reply to firm 2's sales decisions, since firm 1 cannot increase its payoff by choosing any other t . Neither a low-cost nor a high-cost type firm 1 can increase its profit by misleading firm 2 about firm 1's true type. Similarly, firm 2's equilibrium sales are best replies to firm 1's equilibrium strategies. In the proof it is crucial to check in the belief function whether a deviation of t changes the beliefs employed in the deviation profit ($t < t^*$) and whether firm 2 stops subcontracting ($t > 1$). Secondly, take the equilibrium strategies as given. Then the beliefs have to be self-fulfilling.

The proof of *uniqueness* of the separating equilibrium requires applying the refinement of the "intuitive criterion". For details of the proof see appendix (A.1). ■

Remark 1 In region *Ib*, the separating equilibrium subcontracting price $t^* = t_l^* = t_{\max 2}$ is less than 1 (which is the full information subcontracting price), see $t_{\max 2} < 1$ according to equation (A.13). In region *IIb*, the separating equilibrium subcontracting price t^* is below production costs ($t^* = 1 < c_l$).

Summarizing gives the important result for the low-cost firms separating equilibrium subcontracting price $t^* = t_l^*$ in figure (2.1). This figure is the core of this chapter. It not only shows the equilibrium price t^* for the unique separating equilibrium for each cost realization, it also contains all the necessary information for welfare comparisons.

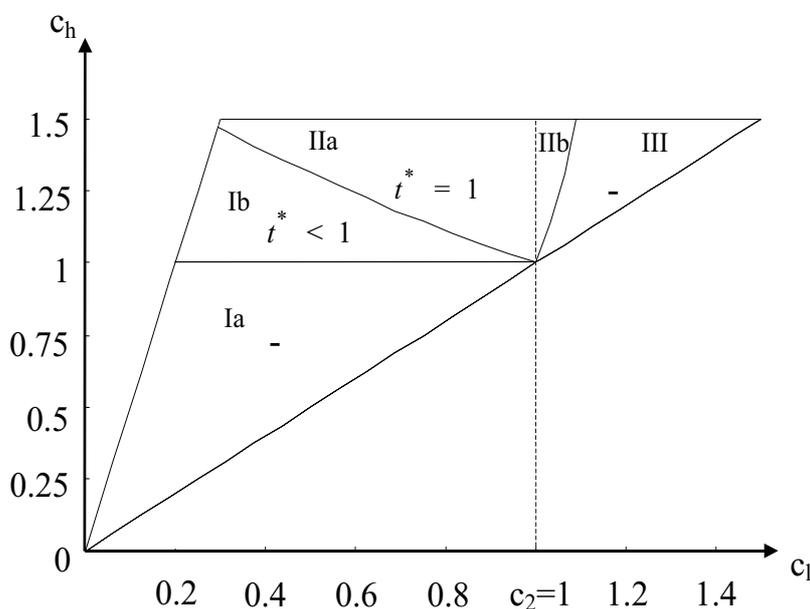


Figure 2.1: Separating equilibrium subcontracting price t^*

Figure (2.1) shows the optimal subcontracting price t^* for every possible cost realization of c_l and c_h . The different regions have different interpretations.

In *region Ia*, a separating equilibrium does not exist. The low-cost as well as the high-cost type firm 1 have production costs which are less than the production costs of firm 2 ($c_l, c_h < c_2 = 1$). The advantage of misleading beliefs is outweighed by the possibility of selling at a high subcontracting price of 1. A low-cost firm would have to set a very low price t_l if it wants to

prevent a high-cost firm from mimicking. But at such a low price t_l , the low-cost firm would instead prefer to subcontract (sell) at the highest price $t_l = 1$, making unit profits of $1 - c_l$, even if this would mislead firm 2 to believe that it is buying from a high-cost firm. (Technically, the equilibrium price t_l is an element of an empty interval, see equation (A.13) and the remarks concerning existence). Instead, proposition (4) will show that pooling equilibria exist with both firms choosing $t = 1$.

Region Ib is the most interesting case. The low-cost firm charges a price less than 1, $t^* = t_l^* = t_{\max 2} < 1$, and the high-cost firm charges $t_h = 1$. It is the classical case where the low-cost firm can successfully signal its type and where a low price t^* is determined by the constraint of preventing a high-cost firm from mimicking the low-cost firm. In region Ib, a high-cost firm would make losses $c_h - 1$ per unit from subcontracting, which it would have to recover from the benefits of manipulating beliefs. Misleading beliefs is so profitable that the low-cost firm has to choose a low subcontracting price $t^* < 1$ in order to increase the losses for the high-cost firm and make mimicking unprofitable. An increase in high-costs c_h (and thereby higher losses of a high-cost firm) allows c.p. the low-cost firm to increase its price t^* as well. Only at and above the border between region Ib and II would losses of a high-cost firm be so high that a low-cost firm could charge the highest price at which subcontracting still occurs ($t^* = 1$). The interesting feature is that the signaling costs in region Ib have to be borne by the informed firm 1, not the consumers. This is explained in more detail in the next section comparing welfare.

In *region IIa and IIb* the low-cost firm charges $t^* = 1$ and the high-cost firm charges any price $t_h^* > 1$. It does not matter which price t_h^* is actually chosen, because subcontracting would never occur at any price above 1. This is indicated by the notation $t_h^* = \text{---}$ if $t_h^* > 1$. Region IIb is of special interest because here a low-cost firm would subcontract (sell) at a price below its production cost ($t^* = 1 < c_l$) but revealing its true type outweighs these losses, see remark 1.

In *region III* even this is no longer the case. Both types of firms would incur substantial losses from selling below production costs ($c_l, c_h > t_i = 1$) and a separating equilibrium does not exist.

2.3.4 Pooling equilibria

In a pooling equilibrium the self-selection equilibrium conditions are

$$\pi_1(c_h, t^*, c^e(t^*)) \geq \pi_1(c_h, t, c_h) \quad (2.11)$$

$$\pi_1(c_l, t^*, c^e(t^*)) \geq \pi_1(c_l, t, c_h) \quad (2.12)$$

for all t and with $t_l = t_h = t^*$ and $c^e(t^*) = \mu_l(t^*)c_l + \mu_h(t^*)c_h = p_l c_l + p_h c_h$. Solving yields the pooling equilibria.

Proposition 4 (*Pooling equilibria*) *The following beliefs and strategies are the perfect Bayesian pooling equilibria in which subcontracting occurs:*

$$\mu_l(t) = \begin{cases} p_l & \text{if } t = t^* \\ 0 & \text{if } t \neq t^* \end{cases} \quad (\text{equilibrium beliefs})$$

$$t_l^* = t_h^* = t^* = \begin{cases} 1 & \text{if region } I_{\text{pooling}} \\ \text{no offer} & \text{if otherwise} \end{cases} \quad (\text{equilibrium prices})$$

with $p_l \in (0, 1)$ and region I_{pooling} as defined in equation (A.20) in appendix (A.2).

Proof. In equilibrium, beliefs and strategies have to be mutually optimal. Similar to the proof of the separating equilibrium the proof consists of two parts. First, take the beliefs as given and show that deviation from the equilibrium strategies is not profitable. Secondly, take the equilibrium strategies as given. Then the beliefs have to be self-fulfilling. Note that subcontracting can only occur at a pooling price $t^* \leq 1$, otherwise firm 2 would prefer to produce on its own. Pooling equilibria at higher prices never lead to subcontracting. For details of the proof see appendix (A.2). ■

Pooling equilibria exist in region I_{pooling} . This region is a subset of region I in figure (2.1), depending on the prior probability p_l . With decreasing prior probability p_l the upper boundaries of region I move inward while the lower boundary doesn't change. For example, if $p_l = 1$, then region I_{pooling} is identical to region I of the separating equilibrium as defined in equation (A.15) and illustrated in figure (2.1). If $p_l = \frac{1}{2}$ the pooling equilibrium conditions (A.20) turn to $c_l \leq c_h \leq \frac{11}{3}c_l$ and $c_h < -\frac{4}{39}(\frac{5c_l}{4} - 2(3 + \sqrt{9 - \frac{15c_l}{4} + c_l^2}))$. This is equivalent to region I in figure (2.1) with both upper boundaries shifted downwards. If $p_l = 0$ the upper boundaries are $c_h \leq 1$ and $c_h < 3c_l$ (instead of $c_h < 5c_l$ in a separating equilibrium). Then region I_{pooling} is a subset merely of region Ia, with the upper boundary shifted downward.

Separating as well as pooling equilibria exist in the overlapping regions of region Ib (separating equilibrium) and region $I_{pooling}$ (pooling equilibria). This depends on the prior probability p_l . In the border case of $p_l = 0$ the regions do not overlap at all. But in all other cases there are at least some overlapping cost regions where separating as well as pooling equilibria exist. It is not possible to "choose" an equilibrium, as they are determined by their belief system. But again the refinement of the "*intuitive criterion*" might eliminate belief systems of the pooling equilibria, at least for a range of prior probabilities p_l . The "*intuitive criterion*" can be outlined as checking the following. Assume a pooling equilibrium where firm 1 chooses an out-of-equilibrium price $t \neq t^*$ in order to convince firm 2 that it is a low-cost firm. Then such a deviation should only be profitable for a low-cost firm and not for a high-cost firm. Technically, the "*intuitive criterion*" can be applied if there exist a t such that

$$\pi_1(c_h, 1, c^e(1)) \geq \pi_1(c_h, t, c_l) \quad (2.13)$$

$$\pi_1(c_l, 1, c^e(1)) < \pi_1(c_l, t, c_l) \quad (2.14)$$

which might hold for a range of prior probabilities p_l . If the conditions hold, a deviation is only profitable for a low-cost firm and the beliefs should accordingly assume a low-cost firm *with certainty*. This is not the case in a pooling equilibrium and therefore these beliefs and equilibria can be eliminated. (In the other range of prior probabilities applying the "*intuitive criterion*" would be inconclusive).

In order to check whether there exists a range of prior probabilities p_l which fulfill both equations it is necessary to choose particular values for c_l and c_h from the overlapping regions. Calculations for different values show that there exist prior probabilities for which both equations do not hold. The "*intuitive criterion*" is not able to eliminate all pooling equilibria.

Proposition 5 (*Equilibrium selection*) *Separating and pooling equilibria exist in the overlapping regions of Ib and $I_{pooling}$.*

Proof. See above.

2.4 Welfare comparison with information sharing equilibria

Information sharing agreements between competitors are a means to reach complete information.

Firms have to decide whether to join a trade association (market information system) before they know e.g. their cost realization. Then firms get to know their costs. If they committed to an information sharing agreement the private information is revealed to all firms via the trade association, even if ex post revelation is harmful for a firm. The trade association can verify the private information, e.g. by checking the accounting. Finally, firms compete in the market. The literature focused on the question whether firms would noncollusively commit ex-ante to share information. The results depend on the type of competition, the degree of product heterogeneity and whether the information shared concerns private or common values. In the standard (Cournot) quantity homogeneous goods model, firms would noncollusively share private cost information. Welfare increases but unfortunately consumer surplus decreases. This might be the reason why antitrust authorities tend to forbid information sharing agreements.

It is interesting to compare this reference case of complete information with the case of incomplete information with a signaling equilibrium. With complete information, subcontracting occurs at the highest possible subcontracting price $t = 1$ as long as t is below the firms own production costs ($c_l, c_h < 1$). This is the case in region Ia where both firms subcontract at $t = 1$. In region Ib and IIa only a low-cost firm subcontracts at $t = 1$. In a separating equilibrium a low-cost firm 1 can often only charge a price less than 1 (see region Ib in figure (2.1)). The difference is the signaling cost of a low-cost firm 1, which wants to distinguish itself from a high-cost firm. Signaling costs are the difference $1 - t^*$. They have to be borne by the uninformed firm. Consumers benefit because firm 2 can subcontract (buy) at lower marginal costs and therefore market Cournot quantity increases.

Proposition 6 *The optimal subcontracting price t^* in a separating equilibrium is lower (equal) to the price charged under complete information, see region Ib (region IIa) in figure (2.1) and can be lower than the sellers own production costs (region IIb). These signaling costs have to be borne by the informed firm and benefit consumers through higher market output. Signaling through subcontracting increases consumer surplus and is in this respect*

superior to an information sharing agreement.

2.5 Conclusion

Subcontracting was shown to be a way to signal private information. But the concern, that the nature of competition reduces welfare and consumer surplus, is unwarranted. Instead, for some regions of cost realizations, consumers strictly benefit from signaling through subcontracting when compared to a situation with complete information. The signaling costs of the informed firm are equivalent to lower prices for consumers and consumer surplus increases. In this respect, signaling through horizontal subcontracting is superior to an information sharing agreement. Competition policy should, as far as informational aspects are concerned, allow subcontracting.

Chapter 3

Product variety, capacity and subcontracting in monopoly

3.1 Introduction

Horizontal subcontracting agreements are common in many industries. Firms subcontract production to or from a rival firm even though each firm could produce different products or increase capacity on its own. Anti-trust authorities have always been attentive to these agreements. While they may lead to more production efficiency they might also facilitate collusion.

The European Commission alleges that subcontracting agreements between competitors lead to a division of markets and collusive behaviour. In a decision regarding the European flat glass industry it forbids cross-supplies between Italian glass producers. The European court reversed the Commission's decision because the Commission had failed to prove the existence of an institutionalized system for glass exchange (European Commission, 1988, European Court, 1992). So the question remains unresolved. Instead, companies have grown more hesitant to openly engage in subcontracting agreements. In the United States, the Department of Justice in its first report to the Senate on the National Cooperative Research and Production Act hoped that by the time of the next triennial report the (filed) joint production ventures will be in actual operation so that their impact on competitiveness can be assessed (Department of Justice, 1996).

This chapter analyzes how subcontracting agreements between competitors influence competition and welfare when firms face lumpy investments.

In particular, when do firms have a noncollusive interest to subcontract and would consumers benefit from this practice as well?

The model considers an industry with capital-intensive production in plants of a given size with high fixed costs. Due to lumpy investments firms will at different demand levels typically be either capacity constrained or have excess capacity. This is characteristic of the flat glass industry, but it also applies e.g. to the aluminium, steel and chemical industry.

In a duopoly firms decide on product variety and capacity, that is the number of different products and the number of plants. Each firm can produce either one or two different products in one or two plants. Changing the product line in a plant or building a new plant incurs different kinds of fixed costs. In the first stage firms choose a product-plant mix. They then engage in a subcontracting stage and a (Cournot) quantity-setting stage. If firms subcontract, one firm sets a price at which the rival firm in the quantity-setting stage can buy (instead of having to produce) some or all of this products output.

Firms' optimal product and capacity decisions vary with the level of demand. Firms start out producing one product in one plant. They have the possibility to sell a second product and to increase capacity. Adjustments in product variety and capacity occur at different levels of demand. The cases with and without subcontracting will be compared under welfare aspects.

Subcontracting presents a trade-off between efficiency gains and collusive effects. Firms can increase production efficiency by saving fixed costs when choosing a different product-plant combination. This change of the cost structure affects competition and output in three different ways. These shall be called the specialization, the capacity and the subcontracting effect.

Specialization of firms occurs when one firm stops producing one product on its own, e.g. to save fixed costs of switching the product line, and does not or only partially subcontract the product instead. Firms would thereby concentrate on different markets. One firm will always benefit, at the extreme it will gain a monopoly for one product, and the other firm and consumers will always be worse off. This is the anti-trust concern about a collusive division of markets. The capacity effect occurs when the change of the product-plant combinations lifts capacity constraints in the production of one or both products. It is always beneficial for both firms and for consumers. In the subcontracting literature capacities and non-convexities of costs have not been considered - even though these are common features in many industries. The subcontracting effect influences industry output and prices via the

subcontracting price and the subcontracted quantity, with which the buying firm competes directly against the selling firm. The selling firm is always worse off, the buying firm and consumers benefit. The interaction of these effects under the prevailing market characteristics, in particular the demand level and the degree of excess capacity, determine the welfare implications.

The results are ambiguous. If subcontracting is not allowed both firms change product variety and capacities at the same demand levels. There are big fluctuations in the market, firms switch from having binding capacity constraints to large excess capacities. Specialization in products and plants would often be Pareto dominant for firms and consumers but cannot be attained as noncooperative Nash-equilibria. This changes with subcontracting. Specialized product-plant combinations can also be equilibria. One firm can compensate the other firm through the price and quantity of the subcontracted product for not producing another product or building a new plant. But at the same time the subcontracting mechanism changes the equilibrium output and price and reduces the incentive for the subcontracting (selling) firm to participate. The reason is that the capacity effect only dominates the subcontracting effect at high demand levels. Yet at these high demand levels consumers would be better off without subcontracting. With subcontracting either only firms or only consumers are better off, but never both.

Welfare is almost always higher at (low) demand levels, where firms lack the incentive to noncollusively engage in subcontracting. Here it would make sense for anti-trust authorities to supervise and enforce specialisation (and rationalization) "cartels" instead of hoping for subcontracting as a market mechanism. It is a different question if the potential gains justify the negative implications which can be expected from the informational requirements and institutional dynamics of such market interventions. Welfare is sometimes higher at (high) demand levels where firms noncollusively subcontract. Unfortunately, consumers would be worse off. If consumer surplus is the main criterion for competition policy then subcontracting should not be allowed.

While the results indicate a collusive character of subcontracting it is crucial to keep in mind that the results were derived with assumptions, which are most unfavourable to subcontracting. Most importantly, marginal costs are identical and do not change with subcontracting (as they could with economies of scale of learning). This eliminates the efficiency gain of equalizing marginal costs, typically the driving force for subcontracting. Focusing instead on capacity competition and non-convexities of costs as in this chapter, reverses the welfare effects for consumers. Furthermore, assuming

complementary instead of independent products on the demand side would increase the incentive for firms to increase product variety and output and enhance subcontracting as well.

Related literature in subcontracting includes Kamien, Li and Samet (1989) and Spiegel (1993). Kamien, Li and Samet (1989) study how the possibility of subcontracting production influences competition of two rival firms for a contract or a market in an auction. The firm with the lowest bid wins a contract and can subcontract production to the loser. Firms behaviour changes even if they do not engage in subcontracting, and if they do, firms bid less aggressively if the loser sets the subcontracting terms. In contrast, Spiegel (1993) allows for the possibility of each firm accessing the product market on its own. Then horizontal subcontracting between rival firms can allocate production more efficiently between them and for a wide range of parameters enhance industry output and welfare. In both articles, asymmetric convex costs are the crucial assumption. This chapter, in contrast, considers capacity competition and non-convexity of costs.

In the literature on production joint ventures Gale (1994) shows that if firms choose an aggregate level of capacity and are able to utilize unused capacity of the other firm by means of a use-or-loose provision, firms quote socially optimal prices. This requires production to be overseen by an independent management company. Breshnahan and Salop (1985) are an example of a strand of literature where financial and control arrangements between firms determine the competitive incentives of parent and rival firms. Subcontracting differs from this literature on production joint ventures through the fact that firms are independent and maintain separate production before competing directly in the final marketplace. The literature on lumpy investments usually looks at timing decisions of an investment.

The chapter is organized as follows. The monopoly case is introduced in section (3.2) to illustrate the relevant effects and prepare for the duopoly case. The basic model is described in section (3.2.1) and states the profits for the cases of one and two plants. In the following, they will determine the equilibrium capacity choice, that is the number of plants, of a monopolist for two cases. First, in section (3.2.2), capacity will be determined for each level of a growing demand with exogenously given technology (that is plant size K and the fixed cost disadvantage of building a new plant F). This is also the relevant case dealt with in the duopoly. The case will further distinguish between symmetrically and asymmetrically growth in the two considered markets. Secondly, in section (3.2.3), monopoly equilibrium

capacities will be determined for different technologies for any exogenously given level of demand. Section (4.1) contains the duopoly case. Here, section (4.1.1) deals with product and capacity decisions without subcontracting and section (4.1.3) looks at product and capacity decisions with subcontracting. Finally, welfare implications are dealt with in section (4.1.4). A discussion follows in section (4.1.5).

3.2 Monopoly

The monopoly case is well-suited to illustrate the relevant effects and to prepare for the more concise notation of the duopoly case.

Consider a monopolist with one plant in which he produces two independent products, x and y . When will he invest in a second plant and what are the welfare effects?

The European Commission alleges that subcontracting agreements between competitors lead to a division of markets and collusive behaviour. This model looks at the trade-off between efficiency gains and effects due to a division of markets.

Due to technology, assume that there will only be capital-intensive production plants of a given size with high fixed costs. Typically, demand will be such that there is either excess capacity or capacity constraints are binding. In contrast to the literature on lumpy investment (usually considering either the timing decision of investments or determining the capacity in a duopoly) capacity is not necessarily fully utilized. In contrast to the literature on subcontracting marginal production costs are the same for both firms. Instead, efficiency gains from subcontracting derive from capacity restrictions.

3.2.1 The Model

Consider an industry with two firms, 1 and 2. Each firm can produce one or both of the two products, x and y . The inverse demand functions for the products are

$$\begin{aligned} P(x_1, x_2) &= a_1 - (x_1 + x_2) + c(y_1 + y_2) \\ P(y_1, y_2) &= a_2 - (y_1 + y_2) + c(x_1 + x_2) \end{aligned}$$

For $c > 0$ ($c < 0$) the two products are complements (substitutes), while for $c = 0$ they are independent.

Due to technology only lumpy investments in capacity are possible. A production plant has a fixed capacity K with high fixed costs F_n . A firm can not adjust its capacity incrementally. A production plant can be used to produce either product x or product y at zero marginal cost upto capacity and infinite marginal cost thereafter. A firm can also produce both products in one plant but then incurs additional fixed costs of changing the product line, F_w . It will be assumed that building a completely new plant will lead to higher fixed costs than changing the product line in an existing plant, so that $F_n > F_w$. Thus, the cost of producing output levels x and y is

$$C(x, y) = \begin{cases} F_n & \text{if } 0 < x \leq K, y = 0 \text{ or } 0 < y \leq K, x = 0 \\ F_n + F_w & \text{if } x, y > 0, x + y \leq K \\ \infty & \text{otherwise} \end{cases}$$

with $F_n > F_w$.

Firms can make their investment and production decisions either with or without subcontracting being allowed. With subcontracting, one firm sets a price t at which the rival firm can subcontract a quantity s (i.e. the latter buys an amount s from the former). We will look at ex-ante subcontracting, which means that the subcontracting stage is played before the quantity-setting stage.

Firms play the following game:

1. Firms decide how many plants to build (1 or 2).
2. If subcontracting is allowed, firm 1 sets a price t at which it is willing to sell the product x .
3. Firms engage in Cournot (quantity) competition for products x and y . If subcontracting takes place firm 2 also decides on the subcontracted quantity s .

The solution concept is that of a subgame perfect Nash-equilibrium. Note that even in the subcontracting stage the solution is not cooperative. Firms do not bargain on how to split efficiency gains.

The results will crucially depend on whether there is excess capacity or a binding capacity constraint. This is determined by the relationship of demand (market size a_1 and a_2) to the technologically given plant capacity K . Furthermore, for the decision whether to build a new plant or to possibly produce both products in an existing plant, the difference of fixed costs $F = F_n - F_w$ will be important.

The results will be derived for all possible parameters. These results will be illustrated for two cases. In the first case, demand levels a will vary and the technological parameters (plant size K and fixed costs parameters F_n and F_w) will be held constant. Then, in a first example, demand will symmetrically increase in both markets to the same degree. In a second example, demand will asymmetrically only increase in one market.

The investment decision and the welfare implications will first be discussed for the monopoly and then for the duopoly.

One Plant

In the first case the monopolist produces products x and y in one plant. The profit function is¹

$$\pi^{xy} = (a_1 - x)x + (a_2 - y)y - C(x, y) \quad s.t \quad x + y \leq K.$$

The quantities and the payoff function depend on whether capacity constraints are binding or not.

If $\frac{a_1+a_2}{2} \leq K$ then capacity constraints are not binding and $x^* = \frac{a_1}{2}$ and $y^* = \frac{a_2}{2}$.

If $K < \frac{a_1+a_2}{2}$ then capacity constraints are binding and $x^* = \frac{1}{4}(2K + a_1 - a_2)$ and $y^* = \frac{1}{4}(2K - a_1 + a_2)$.

Therefore profits can be written as

$$\pi^{xy} = \begin{cases} \frac{1}{8}(a_1 - a_2)^2 + \frac{1}{2}K(a_1 + a_2) - \frac{1}{2}K^2 - F_n - F_w & \text{if } 0 < K < \frac{a_1+a_2}{2} \\ (\frac{a_1}{2})^2 + (\frac{a_2}{2})^2 - F_n - F_w & \text{if } \frac{a_1+a_2}{2} \leq K \end{cases} \quad (3.1)$$

Two Plants

Now the monopolist produces product x in one plant and product y in a second plant. The profit function is

$$\pi^{x,y} = (a_1 - x)x + (a_2 - y)y - C(x, y) \quad s.t \quad x \leq K, y \leq K$$

¹Superscripts indicate which products are being produced, π^{xy} , separated by a comma if produced in two different plants, $\pi^{x,y}$. So $\pi^{xy,y}$ means that the firm has two plants, in the first it produces products x and y , in the second plant it produces product y .

In order to determine the payoff function the cases have to be distinguished where none, only one or both of the two plants are capacity constrained.

If $\frac{a_1}{2} \leq K$, $\frac{a_2}{2} \leq K$ then none of the capacity constraints are binding and $x^* = \frac{a_1}{2}$ and $y^* = \frac{a_2}{2}$.

If $\frac{a_2}{2} \leq K < \frac{a_1}{2}$ then production of product x is capacity constrained and production of product y is not. Then $x^* = K$ and $y^* = \frac{a_2}{2}$.

If $\frac{a_1}{2} > K$, $\frac{a_2}{2} > K$ production of both products is capacity constrained and $x^* = K$ and $y^* = K$.

Profits are:

$$\pi^{x,y} = \begin{cases} (a_1 + a_2 - 2K)K - 2F_n & \text{if } \frac{a_1}{2} > K, \frac{a_2}{2} > K \\ (a_1 - K)K + \left(\frac{a_2}{2}\right)^2 - 2F_n & \text{if } \frac{a_2}{2} \leq K < \frac{a_1}{2} \\ \left(\frac{a_1}{2}\right)^2 + \left(\frac{a_2}{2}\right)^2 - 2F_n & \text{if } \frac{a_1}{2} \leq K, \frac{a_2}{2} \leq K \end{cases} \quad (3.2)$$

Equilibrium capacities

The equilibrium capacities, that is the number of plants, chosen by the monopolist depend on the demand parameters market sizes a_1 and a_2 and the technology parameters K , F_n and F_w . To interpret the results, one set of parameters has to be held constant. Two cases are conceivable. First, equilibrium capacities can be determined for varying demand and given technology, or secondly, for varying technology at given demand levels.

The first case will be more relevant. Typically, the technology parameters are exogenously given and do not change over time quickly, while demand may fluctuate or experience slow and steady growth. So in the monopoly and the duopoly case it will be assumed that the technology parameters are given and profits and plant investment decisions are then calculated for all possible values of demand. This can be interpreted as looking at the dynamics of a growing demand. Two examples will be distinguished. In the first example, markets will be assumed to be of equal size, $a_1 = a_2 = a$. Demand for product x and demand for product y increase at the same rate. In the second example demand will only increase for product x while demand for product y will be held constant. This allows for asymmetric market sizes.

The second case will be dealt with for the monopoly case to give a better intuitive understanding for the relevant parameters. Equilibrium capacities will be determined for varying technological parameters for any exogenously given level of demand. This can be interpreted as a mature market where

firms have to choose their capacity (number of plants) which is most profitable in the case of variable technology and a given level of demand.

Both cases will the prices consumers face and conclude with the welfare effects for consumers and society.

3.2.2 Equilibrium capacities for growing demand

The case of growing demand in markets of equal size will also be the "workhorse" example for the duopoly and subcontracting cases.

Markets are of equal size, so that $a_1 = a_2 = a$. In what follows a will be the variable parameter of interest. Capacity parameters are exogenously normalized to $K = 1$, $F_n = 0,25$ and $F_w = 0,05$. The choices can be motivated as follows. Economically important is the ratio of demand a to plant capacity K . As long as demand varies, this ratio will also vary for any exogenously given K . As to the choice of fixed costs F_n for building a new plant and the fixed costs F_w for switching the product line in an existing plant, the important parameter is the "disadvantage" of building a new plant $F = F_n - F_w$. This difference affects the critical value of demand at which investing in a second plant or subcontracting will occur. The fixed costs F_n are chosen as to allow for positive profits. They are exactly half the size of the maximal profits of an unconstrained monopolist. The fixed costs of changing the product line F_w are substantially less than the fixed costs F_n of building an entirely new plant.

Then using equations (3.1) and (3.2) profit with one plant is

$$\pi^{xy} = \begin{cases} \frac{1}{2}a^2 - F_n - F_w & \text{if } 0 < a \leq 1 \\ a - \frac{1}{2} - F_n - F_w & \text{if } 1 < a \end{cases} \quad (3.3)$$

and profit with two plants is

$$\pi^{x,y} = \begin{cases} \frac{1}{2}a^2 - 2F_n & \text{if } 0 < a \leq 2 \\ 2a - 2 - 2F_n & \text{if } 2 < a \end{cases} \quad (3.4)$$

Comparing the two profit functions yields that the monopolist invests in a second plant when demand is larger than a^* .

What determines the demand intercept a^* at which the monopolist switches from producing both products in one plant to production with two plants?

In general it is profitable to run two plants if the profit difference $\Delta\pi = \pi^{x,y} - \pi^{xy}$ is positive. Using equations (3.3) and (3.4) this yields:

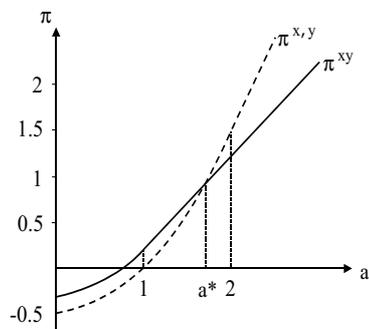


Figure 3.1: Monopoly profits as a function of demand with the number of products per plant as indicated

$$\Delta\pi = \begin{cases} -F & 0 < a \leq 1 \\ \frac{1}{2}(a-1)^2 - F & 1 < a \leq 2 \\ a - \frac{3}{2} - F & 2 < a \end{cases} \quad (3.5)$$

The profit difference will never be positive for $0 < a \leq 1$ because $-F < 0$. For $1 < a \leq 2$, it will only be positive if $a^* > 1 + \sqrt{2F}$. Then switching to two plants will only occur in this interval if $F < \frac{1}{2}$.

Proposition 7 *A monopolist increases his capacity by a second plant if demand a exceeds*

$$a^* = \begin{cases} 1 + \sqrt{2F} & \text{if } F < \frac{1}{2} \\ \frac{3}{2} + F & \text{if } F \geq \frac{1}{2} \end{cases} \quad (3.6)$$

If the disadvantage in fixed costs for investing in a new plant is not too high ($F < \frac{1}{2}$) the monopolist will have excess capacity.

Proof. *Solve equation (3.5) for a . If $F < \frac{1}{2}$ then $1 < a^* \leq 2$ and the two-plant monopolist is not capacity constrained and has excess capacity. ■*

If the disadvantage in fixed costs F is not extremely large ($F < \frac{1}{2}$) then $1 < a^* \leq 2$. This lends itself to an easy interpretation.

If demand is low relative to capacity, $a \leq K = 1$, then neither the one-plant nor the two-plant monopolist is capacity constrained. They have

the same profits except that the two-plant monopolist has higher total fixed costs, thus leading to a negative profit difference, $-F < 0$. It will always be better to produce in one plant. If $a > 1$, the one-plant monopolist is capacity constrained. He can start charging higher prices but cannot expand output. The two-plant monopolist can increase prices and output until he reaches the monopoly output $a = 2$ beyond which he would also be capacity constrained. For $a > 2$, unless the fixed cost difference F is extremely large, it will always be more advantageous to be a constrained two-plant monopolist than being a constrained one-plant monopolist with total capacity only half as large. So switching from one regime to another will occur in the interval $1 < a^* \leq 2$. It is another straightforward result that switching will occur later if the fixed costs for a new plant, F_n , and thereby also the fixed cost disadvantage, F , increase.

Remark 2 *The critical demand a^* , at which a monopolist invests in a second plant, increases with the fixed cost (disadvantage) of building a new plant.*

Proof. From (3.6) it is clear that $\frac{\partial a^*}{\partial F} > 0$ for all F . ■

Prices for the two products are identical and depend on the state of demand, the number of plants and the number of products produced per plant. Prices for the one-plant and the two-plant monopolist are as follows

$$p^{xy} = \begin{cases} \frac{a}{2} & \text{if } 0 < a \leq 1 \\ a - \frac{1}{2} & \text{if } 1 < a \end{cases}$$

$$p^{x,y} = \begin{cases} \frac{a}{2} & \text{if } 0 < a \leq 2 \\ a - 1 & \text{if } 2 < a \end{cases}$$

At demand a^* prices will fall:

Social welfare would be higher if the monopolist would switch to the second plant at a lower demand level $a' < a^*$. Social Welfare is the sum of producer and consumer surplus, $W = \pi + CS$. For the consumers it would be better to have a two-plant monopolist than a one-plant monopolist because prices would be lower, see figure (3.2). So switching later, that is $a' > a^*$, would be worse for firms and worse for consumers. Switching earlier, that is $a' < a^*$, would be worse for firms but better for consumers, and in fact social welfare would be higher.

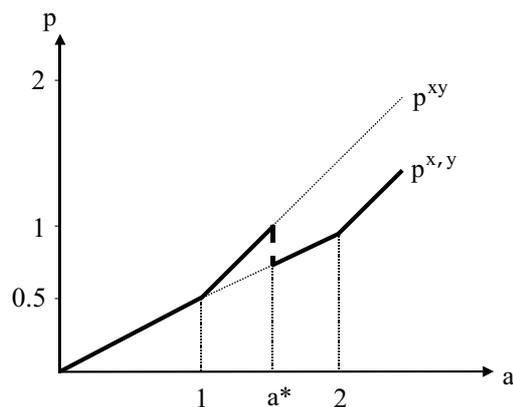


Figure 3.2: Monopoly prices as a function of demand a and number of products per plant as indicated

Consumer surplus is

$$CS = \int_0^{x^*} p(x) dx - p^* x^*$$

For the one-plant monopolist this is

$$CS^{xy} = 2 \left(\left[ax - \frac{1}{2} x^2 \right]_0^{\frac{1}{2}} - \left(a - \frac{1}{2} \right) \frac{1}{2} \right) = \frac{1}{4} \quad (3.7)$$

and for the two-plant monopolist

$$CS^{x,y} = 2 \left(\left[ax - \frac{1}{2} x^2 \right]_0^{\frac{a}{2}} - \left(a - \frac{a}{2} \right) \frac{a}{2} \right) = \frac{1}{4} a^2 \quad (3.8)$$

The welfare optimal demand a' for switching to two plants would then be, using $F < \frac{1}{2}$ and equations (3.5), (3.7) and (3.8):

$$\Delta W = \pi^{x,y} + CS^{x,y} - \pi^{xy} - CS^{xy} = \frac{1}{2}(a-1)^2 - F + \frac{1}{4}(a^2-1)$$

This leads to $a' = \frac{2}{3} + \frac{1}{3}\sqrt{1+12F}$ and $a' < a^* = 1 + \sqrt{2F}$. In the example, welfare optimal switching would occur substantially earlier at $a' = 1,28$ instead of $a^* = 1,63$.

Proposition 8 *Welfare optimal switching to two plants would occur earlier and at a lower critical demand a' than at the demand level a^* at which the monopolists switches.*

Proof. For $F < \frac{1}{2}$ it holds that $a' < a^*$, see above. ■

3.2.3 Equilibrium capacities for varying technologies

Now assume that demand is exogenously given at $a_1 = a_2 = 1$ and that the capacity parameters plant size K and fixed cost disadvantage F may vary.

Then the profit functions (3.1) and (3.2) become

$$\pi^{xy} = \begin{cases} K - \frac{1}{2}K^2 - F_n - F_w & \text{if } 0 < K < 1 \\ \frac{1}{2} - F_n - F_w & \text{if } 1 \leq K \end{cases}$$

and

$$\pi^{x,y} = \begin{cases} (2-2K)K - 2F_n & \text{if } 0 < K < \frac{1}{2} \\ \frac{1}{2} - 2F_n & \text{if } \frac{1}{2} \leq K \end{cases}$$

It is more profitable to run two plants if $\Delta\pi = \pi^{x,y} - \pi^{xy}$ is positive:

$$\Delta\pi = \begin{cases} K - \frac{3}{2}K^2 - F & \text{if } 0 < K < \frac{1}{2} \\ \frac{1}{2} - K + \frac{1}{2}K^2 - F & \text{if } \frac{1}{2} \leq K < 1 \\ -F & \text{if } 1 \leq K \end{cases}$$

Figure (3.3) shows in which region two plants would be more profitable. If fixed costs for a new plant are very high, then firms will always only invest in one plant.

The prices of the two products are identical because the markets are of equal size. The price for a product depends on the plant size K , the number of plants and the products produced in each plant.

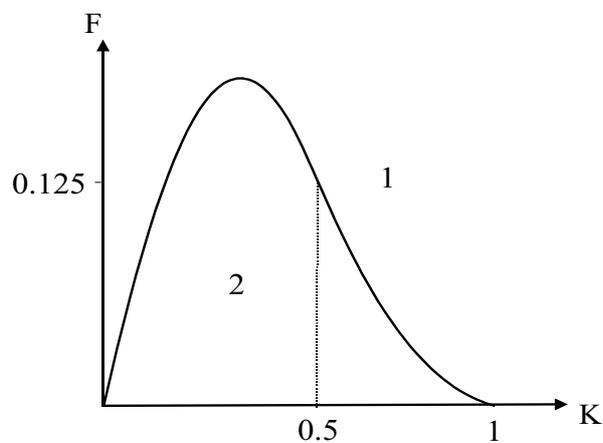


Figure 3.3: Optimal number of plants as a function of F and K

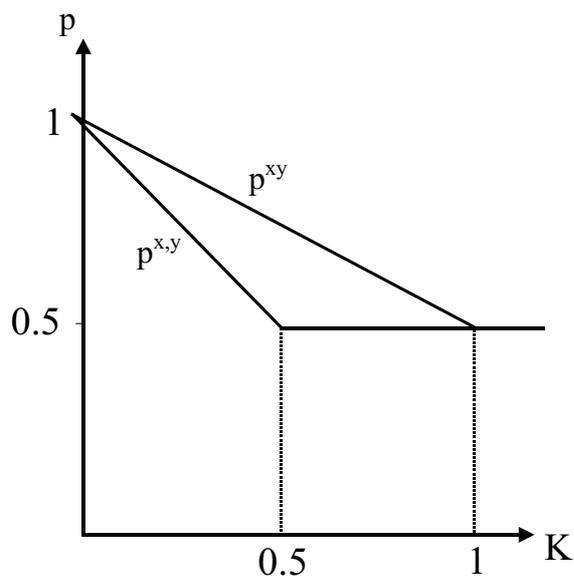


Figure 3.4: Monopoly prices as a function of K with the number of products per plant as indicated

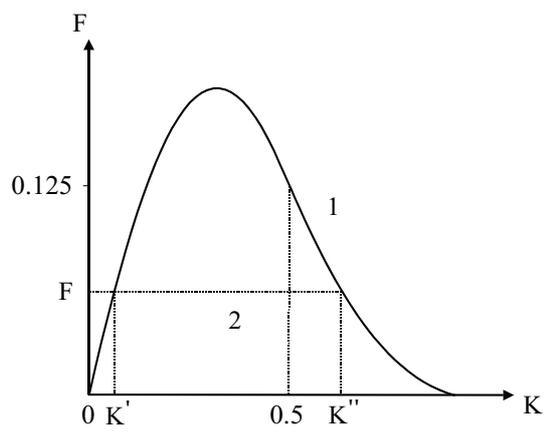


Figure 3.5: Optimal number of plants as a function of F and K

Now assume that the fixed cost disadvantage F is also exogenously given. Then the monopolist will prefer one plant only if the capacity of one plant, K , is very small or very large, see figure (3.5).

If $K < K'$, neither the one-plant nor the two-plant firm is capacity constrained. Running one plant is more profitable because even though the two-plant firm's total capacity is twice as high there are no additional sales to cover the additional fixed costs.

If $K > K'$, the one-plant firm's capacity constraint is getting less and less severe. Its disadvantage of lower total output vanishes completely for $K > K''$. The two-plant firm's output advantage is no longer bigger than the fixed cost disadvantage.

For consumers, this leads to the result that for big plant sizes, $K > K''$, the price would be higher than for a broad range of smaller plant sizes, a result which is at first counterintuitive. If plant sizes are "too" big a firm could not cover the additional fixed costs and would rather sell a lower quantity. Firms do not take into consideration the loss of consumer surplus.

The corresponding prices are illustrated in figure (3.6).

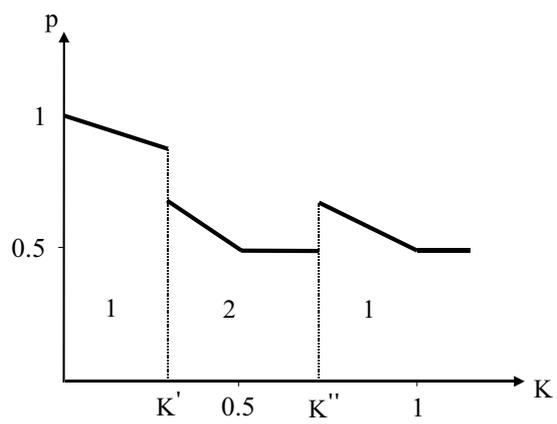


Figure 3.6: Monopoly prices as a function of K and products per plant as indicated

Chapter 4

Product variety, capacity and subcontracting in duopoly

4.1 Duopoly

4.1.1 The Model

Consider an industry with two firms, 1 and 2, which can produce one or two products, x and y . The inverse demand functions for the products are linear, the products are independent and the markets of the two products are of equal size. Due to technology, only lumpy investments in capacities are possible. A firm can not adjust its capacity incrementally. A production plant has a fixed capacity K and high fixed costs F_n . A production plant can be used to produce either product x or product y at zero marginal costs up to capacity and infinite marginal costs thereafter. A firm can also produce both products in one plant but then the firm incurs fixed costs of changing the product line F_w . The fixed cost of the first plant will be assumed to be sunk (see appendix B.1.3 for the technical reasons). Increasing capacity by building a completely new (second) plant leads to higher fixed costs than changing the product line, that is $F_n > F_w$. Thus, the cost of producing output levels x and y is

$$C(x, y) = \begin{cases} 0 & \text{if } 0 < x \leq K, y = 0 \text{ or } 0 < y \leq K, x = 0 \\ F_w & \text{if } x, y > 0, x + y \leq K \\ F_n & \text{if } x, y > 0, x + y > K, x \leq K \\ F_n + F_w & \text{if } x, y > 0, x > K \\ \infty & \text{otherwise} \end{cases}$$

Due to symmetry there will often be two asymmetric equilibria. We will without loss of generality concentrate on one of these equilibria. Firms start out producing one product in one plant. We will assume that firm 1 produces product x and firm 2 produces product y . Firms make product and capacity decisions either with or without subcontracting. We will only consider ex-ante subcontracting, where the subcontracting stage precedes the quantity-setting stage. The game with subcontracting involves three stages:

Stage 1: Product and capacity decisions: Firms decide on the number of products they wish to sell and the number of plants, that is whether or not to build a second plant.

Stage 2: Firm 1 chooses a subcontracting price t , at which firm 2 can subcontract (buy) product x .

Stage 3: Cournot (quantity) competition. Firms decide how much to produce of each product and firm 2 also decides on s , the quantity of product x it buys.

The payoff functions depend on the number of products and plants and on the corresponding capacity constraints. The solution concept is that of a subgame perfect Nash-equilibrium.

4.1.2 Product and capacity decisions without subcontracting

The two firms can choose between two strategies as to the number of products and number of plants. But it is not necessary to look at every theoretically possible product-plant combination. It is for example sufficient for the question of capacity expansion to reduce the two-plant cases to the combination, where only one product is produced in each plant. Then the game without subcontracting consists of 9 possible outcomes. Due to symmetric payoffs this can be further reduced to 6 outcomes. The normal form game is shown in the following table 4.1.2:

		Firm 2		
		y	xy	x,y
Firm 1	x	(f, f)		
	xy	(g, h)	$\xrightarrow{a_4(=a_1)}$	(k, k)
	x,y	(n, o)	(m, l)	$\xrightarrow{a_3} (p, p)$

Firm 1 can produce product x in one plant (x), both products in one plant (xy) or both products in two different plants (x,y). The profits of the firms are denoted for each possible outcome, first for firm 1 and then for firm 2. For example, if both firms produce one product each they would have the same monopoly profit f. If firm 1 produces both products in two different plants (x,y) and firm 2 produces both products in one plant (xy) profits for firm 1 and firm 2, (m, l) , are

$$m = \max_{x_1, y_1} (a - x_1 - x_2)x_1 + (a - y_1 - y_2)y_1 - F_n \quad s.t. \quad x_1 \leq K, y_1 \leq K$$

$$l = \max_{x_2, y_2} (a - x_1 - x_2)x_2 + (a - y_1 - y_2)y_2 - F_w \quad s.t. \quad x_2 + y_2 \leq K$$

Each profit function is a piecewise defined function. The function changes continuously at each demand level at which either the own or the other firms capacity constraint starts getting binding. The profit functions are described in appendix B.1.1. The arrows in table 4.1.2 indicate at which critical demand a_i a firm would prefer to deviate. For example, in equilibrium (f, f) both firms are a monopolist with one product. For demand levels $a \geq a_1$, firm 1 (and firm 2) would deviate and start to produce the second product as well, the equilibrium switches to the duopoly (k, k) . The noncooperative Nash-equilibria for different states of demand are shown in figure 4.1. They can be interpreted as showing the adjustment process for a slowly growing demand.

Proposition 9 (*Without Subcontracting*)

(i) (*Product decisions*)

Both firms extend their product line at demand levels $a \geq a_1$.

(ii) (*Capacity decisions*)

If $F_w < F_n < F_w + \frac{9}{50}$, both firms increase capacity at demand levels $a \geq a_2$.

If $F_w + \frac{9}{50} \leq F_n$, firm 1 increases capacity at demand levels $a_2 \leq a < a_3$ and both firms increase capacity at demand levels $a_3 \leq a$.

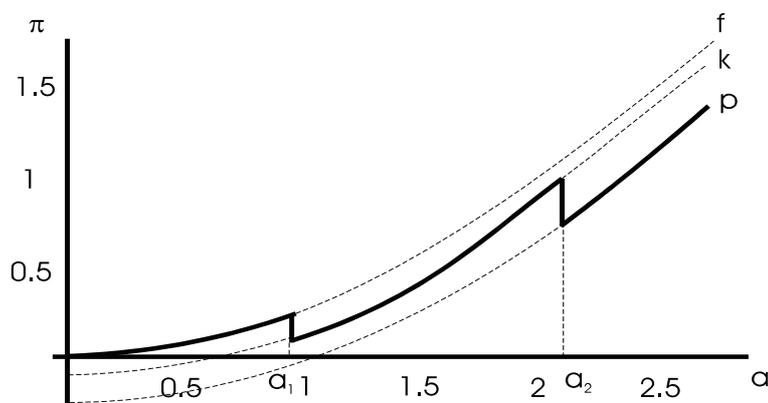


Figure 4.1: Profits, product and capacity decisions without subcontracting

Proof. See appendix B.1 and figure 4.1.

Figure 4.1 can be interpreted as follows. In the normal form game in table 4.1.2, in outcome (f, f) both firms produce one product. Firm 1 would deviate and produce both products if the additional Cournot profit on market y covers the additional fixed costs of changing the product line F_w . Profits with deviation are higher if $g > f$, that is if demand $a > a_1 = 3\sqrt{F_w} = 0.95$. Similarly, firm 2 would deviate and produce a second product if $k > h$, that is if $a > a_4 (= a_1)$. So both firms choose the new strategy of producing both products if demand $a > a_1$. The equilibrium switches from (f, f) to (k, k) .

Furthermore, both firms deviate from outcome (k, k) and increase their capacity at demand levels $a > a_2$ if $a_2 > a_3$. The profit of firm 1 is higher if $m > k$ ($a > a_2$) and the profit of firm 2 is higher if $p > l$ ($a > a_3$). If the condition $a_2 > a_3$ holds, then both firms increase capacity at the same demand levels. Once firm 1 increases its capacity, demand is high enough for firm 2 to increase its capacity as well. This is not necessarily the case because firm 2's marginal profit is different from firm 1's marginal profit when deviating as industry output in (k, k) is different from industry output in (m, l) . For both firms the increase in profit has to cover the additional fixed cost of building a new plant $F_n - F_w$. Therefore fixed costs for a new plant may not be too high relative to the fixed costs of changing product line. The condition $a_2 > a_3$ is equivalent to $F_w < F_n < F_w + \frac{9}{50}$. If this condition is not met, then firm 1 and firm 2 increase capacity at different states of demand. The equilibrium would first move from (k, k) to (m, l) and

then to (p, p) .

A comparison of the outcomes in table 4.1.2 shows that there exist Pareto dominant outcomes at which firms and consumers would be better off than with the noncooperative Nash-equilibria. For example, firms' total profit in the "specialized" outcome (n, o) is always higher than in the equilibrium outcome (k, k) . For consumers the specialized outcome is always at least as good as the equilibrium outcome. At low demand levels consumers would be indifferent, because with excess capacity in both outcomes industry output would be the same. At higher demand levels the equilibrium outcomes get capacity constrained first. Industry output in the specialized (unconstrained) outcome would be higher.

Unfortunately, the Pareto dominant outcome is no equilibrium. Without transfer payments one firm would be better off ($n > k$) but the other firm would be worse off ($o < k$) and would not specialize. The question is whether subcontracting is a mechanism for firms to noncollusively turn a Pareto dominant outcome into an equilibrium and whether consumers would benefit as well.

4.1.3 Product and capacity decisions with subcontracting

Firms' decisions to increase product variety or capacity change when subcontracting is allowed. Without subcontracting both firms increase product variety and capacity at the same demand levels. With subcontracting firms could share product variety or capacity during intermediate levels of demand. Firms could save fixed costs but would also change competition on the output markets. It is not clear whether firms have a noncollusive interest to engage in subcontracting. Therefore, the equilibria of the game with subcontracting will be determined. The possible outcomes are the same as in table 4.1.2, now with profits denoted with subscript s .

The payoffs of the outcomes with subcontracting are determined by solving the game backwards. In the third (quantity) stage firms choose optimal quantities taking into account capacity constraints and given the product-plant decisions and the subcontracting price t . For example, if both firms produce both products in one plant, firms choose optimal quantities

$$\begin{aligned} \max_{x_1, y_1} \pi_1^s(x_1, y_1, s, x_2, y_2 | t) \quad & s.t. \quad x_1 + y_1 + s \leq K \\ \max_{x_2, y_2, s} \pi_2^s(x_1, y_1, s, x_2, y_2 | t) \quad & s.t. \quad x_2 + y_2 \leq K \end{aligned}$$

The optimal quantities $x_1^*(t)$, $y_1^*(t)$, $x_2^*(t)$, $y_2^*(t)$ and $s^*(t)$ depend on whether capacity constraints are binding or not. They have to be calculated for each case where either none, one or both of the firms' plants is capacity constrained. The maximisation also provides the conditions, again as a function of the subcontracting price t , determining which case applies.

Inserting the optimal quantities into the profit function leads to the reduced form game. In the second stage firm 1 chooses the subcontracting price t such that firm 2's profit with subcontracting is at least as high as without subcontracting. If firm 2 is indifferent, firm 2 will by assumption participate in subcontracting:

$$\max_t \pi_1^s(t) \quad s.t. \quad \pi_2^s(t) \geq \pi_2$$

The optimal price $t^*(a)$ is a piecewise defined function of demand a because firm 2's profit without subcontracting is defined differently for different demand levels. Often there are two solutions of price t for a demand region. Only the solutions, at which the subcontracted quantity $s^*(t)$ is positive, can be considered. In the first stage, inserting the optimal price into the profit function for each product-plant outcome yields the payoffs with subcontracting. Comparing the payoffs leads to the Nash-equilibria.

Product decisions with subcontracting

Product decisions of firms change with subcontracting. Instead of increasing product variety at the same demand levels firms could share product variety. Instead of suddenly switching from outcome (f, f) , where each firm sells one product, to outcome (k, k) , where each firm sells both products, firms could share product variety in (g_s, h_s) , see table 4.1.2. At product-plant combination (g_s, h_s) firm 1 produces products x and y in one plant and firm 2 produces product y in one plant. Firm 2 subcontracts (buys) product x from firm 1 and can thereby sell the full range of products.

Profits (g_s, h_s) are determined as follows. In the third stage, firm 1 and firm 2 determine their optimal quantities for each combination of binding and non-binding capacity constraints and the conditions determining which of the cases applies:

$$\begin{aligned}
g_s(x_1, y_1, s, y_2 | t) &= \max_{x_1, y_1} (a - x_1 - s)x_1 + ts + (a - y_1 - y_2)y_1 - F_w \\
&\quad s.t. \quad x_1 + s + y_1 \leq K \\
h_s(x_1, y_1, s, y_2 | t) &= \max_{s, y_2} (a - x_1 - s)s - ts + (a - y_1 - y_2)y_2 \\
&\quad s.t. \quad y_2 \leq K
\end{aligned} \tag{4.1}$$

The optimal quantities are different for each case where either none, one or both firms are capacity constrained. In the second stage, after inserting the optimal quantities into the profit function of each case, firm 1 chooses price t :

$$\begin{aligned}
g_s(t) &= \max_t (a - x_1^* - s^*)x_1^* + ts^* + (a - y_1^* - y_2^*)y_1^* - F_w \\
&\quad s.t. \quad \begin{cases} h_s(t) \geq f & \text{if } 0 < a < a_1 \\ h_s(t) \geq k & \text{if } a_1 \leq a \end{cases}
\end{aligned} \tag{4.2}$$

$$\text{with } h_s(t) = (a - x_1^* - s^*)s^* - ts^* + (a - y_1^* - y_2^*)y_2^*$$

The optimal price $t^*(a)$ is a piecewise defined function of demand a because the profit of firm 2 without subcontracting, f or k , depends on the level of demand. Furthermore, the profit function k is also defined piecewise depending on whether capacity constraints are binding or not. Therefore the optimal price $t^*(a)$ is defined differently for three demand regions (see appendix B.2 for details and the results). With the optimal price $t^*(a)$ for each level of demand it is now possible to check which capacity case applies, that is whether none, one or both firms would be capacity constrained when using the optimal price $t^*(a)$. Inserting the optimal price t into the profit function yields profits (g_s, h_s) for firm 1 and firm 2.

Firms have a noncollusive interest to share product variety if each firm's profit with subcontracting is higher than its profit without subcontracting. Firm 2's profit is at least as high as its profit without subcontracting, this was a condition the optimal price had to meet. In fact, in equilibrium firm 2's profit with subcontracting is always equal to its profit without subcontracting. Then the task remains to check whether firm 1's profit with subcontracting is higher than firm 1's profit without subcontracting. Unfortunately, this only happens to be the case for demand levels, where consumer surplus with subcontracting is lower than consumer surplus without subcontracting ($a \geq a_1$).

Proposition 10 (*Product decisions with subcontracting*)

With subcontracting there is no solution for sharing product variety where firms noncooperatively subcontract and consumer surplus increases. For $a < a_1$ consumers would benefit but firms are worse off, for $a \geq a_1$ firms benefit but consumers are worse off.

Proof. See appendix B.2, the profit functions in figure 4.2 and consumer surplus in figure 4.7.

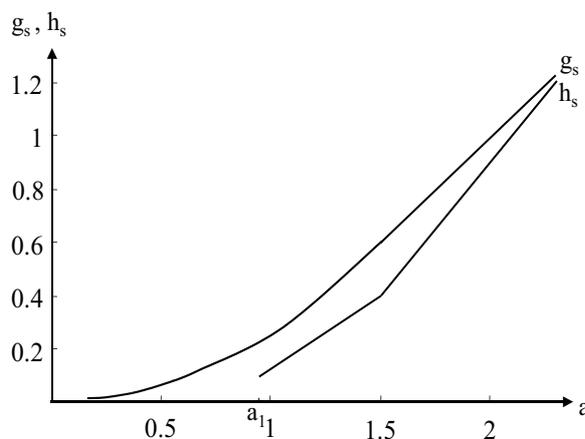


Figure 4.2: Profits, product and capacity decisions with and without subcontracting

Firm 2's profit with subcontracting h_s is equal to its profit without subcontracting, see figure 4.2. Firm 1's profit with subcontracting g_s is equal to its profit without subcontracting for demand levels $a < a_1$, otherwise it is higher.

In figure 4.1, for demand levels $a < a_1$, both firms have monopoly profits f . They do not have an incentive to subcontract because they can not increase their profit above the monopoly level. Firm 1 could choose a subcontracting price such that firm 2 would be indifferent. But then firm 1's profit would be lower than the monopoly profit and firm 1 would prefer not to subcontract in the first place. Consumers would have benefited from subcontracting because output would have increased. For demand levels $a \geq a_1$ firms subcontract. Firm 1 sets a price such that firm 2's profit with subcontracting h_s is equal to its profit without subcontracting k . Firm 1's profit with subcontracting

g_s is higher than its profit without subcontracting k . So both firms participate in subcontracting for these demand levels. Yet consumer surplus with subcontracting will be lower, see figure 4.7.

The results do not depend on the level of fixed costs. An increase in fixed costs of changing the product line F_w decreases only firm 1's subcontracting profit. The profit function g_s would shift downward and as soon as it intersects firm 1's profit without subcontracting, k , firm 1 would no longer have an incentive to subcontract and the equilibrium switches from (g_s, h_s) to (k, k) . In the example, the difference between g_s and k starts getting smaller for $a > 1.5$ because for these demand levels firms without subcontracting are capacity constrained and firm 2 has to be guaranteed a higher profit by firm 1.

Firms' output and industry output with subcontracting are shown in figure 4.3 and figure 4.4.

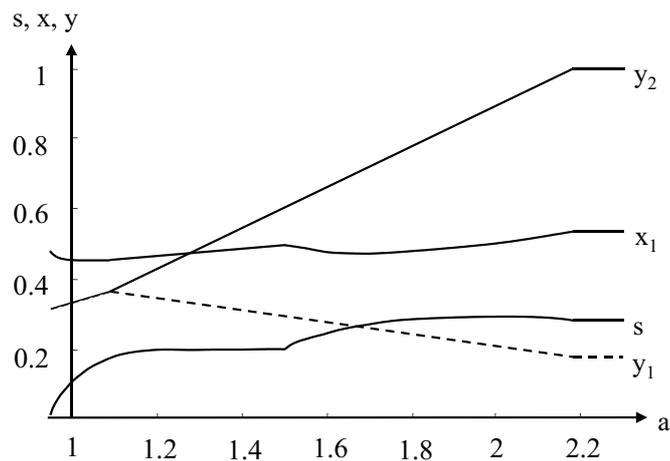


Figure 4.3: Firms' output with subcontracting

There are three critical demand levels at which the optimal output and prices clearly change. First, at $a \geq 1.5$ the profit of firm 2 without subcontracting increases, because firm 2 would be capacity constrained and could raise prices and increase profits more easily. Firm 1 has to subcontract a higher quantity s of product x to firm 2 to keep firm 2 interested in subcontracting and prevent it from starting to produce product x itself. Secondly,

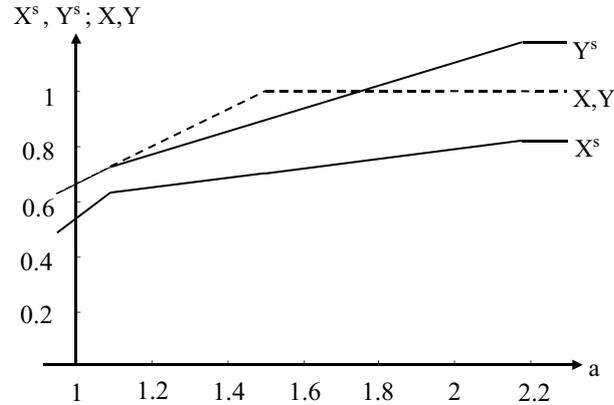


Figure 4.4: Industry output with and without subcontracting

at $a = 1.09$ (only) firm 1 starts getting capacity constrained when subcontracting. An increase in firm 1's production of product x, $x_1 + s$, leads to a decrease in firm 1's production of product y, y_1 . When the subcontracted quantity s of product x increases strongly at $a = 1.5$, the quantity of product x, which firm 1 sells on the market directly, x_1 , decreases strongly as well. Thirdly, at $a = 2.19$ both subcontracting firms start getting capacity constrained. Industry output can no longer increase.

In figure 4.4, industry output with subcontracting, X^s and Y^s , is compared to industry output without subcontracting, X and Y ($X = Y$). Industry output without subcontracting is equal to the capacity of a plant ($K = 1$) for demand levels $a \geq 1.5$. Industry output of product x with subcontracting, X^s , is always less than industry output without subcontracting, X . Industry output of product y with subcontracting, Y^s , is sometimes lower and sometimes higher than industry output of product y without subcontracting, Y .

Prices are illustrated in the following figures.

Figure 4.5 shows, that the price for product x with subcontracting P_x^s is always higher than the subcontracting price t . The difference is firm 2's profit margin for each unit of product x which it subcontracts. Figure 4.6 shows, that prices with subcontracting, P_x^s and P_y^s , are always higher for product x and sometimes higher for product y when compared to the prices

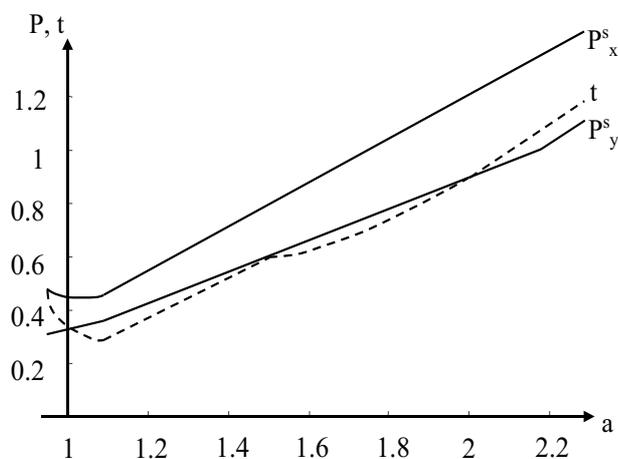


Figure 4.5: Prices with subcontracting and subcontracting price t

without subcontracting, P_x and P_y ($P_x = P_y$). With these results we obtain that basically consumer surplus with subcontracting is lower than consumer surplus without subcontracting, see figure 4.7.

The exception holds for demand levels, at which both firms would be capacity constrained either with or without subcontracting ($a > 2.19$). In both cases the sum of industry output is equal to the sum of industry capacity, which is the size of two plants. The only difference is that with subcontracting industry output of product x and product y would be different. Consumers would prefer asymmetric outputs if total output is fixed. The gain in consumer surplus due to the reduction of one product's price and the increase of this product's quantity outweighs the loss in consumer surplus due to the increase of the other products price and the decrease of the other products quantity. Firms prefer symmetric outputs if total output is fixed. These are interesting results in themselves because the products are independent. Only the fact that total output is fixed due to capacity constraints leads to these different implications for consumers and firms. As a remark, this is exactly opposite to the results when the sum of marginal costs is fixed. In that case firms prefer asymmetry, because cost heterogeneity reduces competition, and consumers prefer symmetry.

But in the case presented here, demand levels with fixed industry output will not be of further interest, because at these high demand levels firms

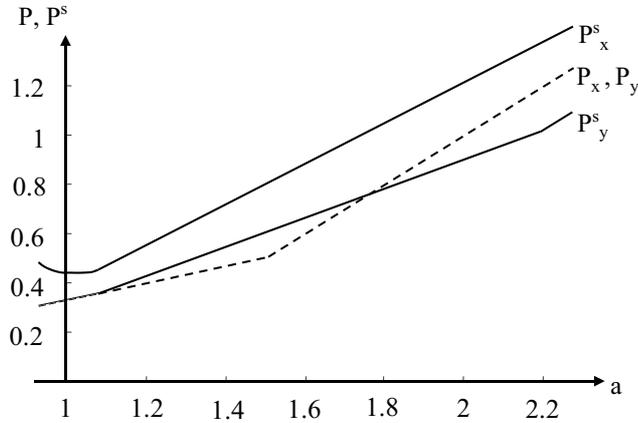


Figure 4.6: Prices with and without subcontracting

would already have switched to an equilibrium where both would have increased their capacity.

Capacity decisions with subcontracting

Capacity decisions of firms change with subcontracting. Instead of being capacity constrained for a wide range of demand levels before suddenly increasing capacity (leading to excess capacity), firms could share the capacity of one additional plant through subcontracting. The equilibrium would be (n_s, o_s) or (m_s, l_s) for some demand levels instead of switching directly from (k, k) to (p, p) , see table 4.1.2. Consumers would benefit if total capacity increases through subcontracting and if this leads to higher industry output. Of particular interest are demand levels, where both firms would be capacity constrained without subcontracting but not yet willing to increase capacity (demand levels $1.5 < a < a_2 \approx 2$ in outcome (k, k) , see figure 4.1). In this demand region, a different product-plant mix would be Pareto dominant for firms and consumers. Total profits (n, o) are higher than total profits (k, k) . This does not hold for the product-plant mix (m, l) , so this outcome is only dealt with in the appendix. In outcome (n, o) industry output is higher as well. The outcome (n, o) would be a Pareto improvement, but it is not a Nash-equilibrium, because without subcontracting one firm would be worse

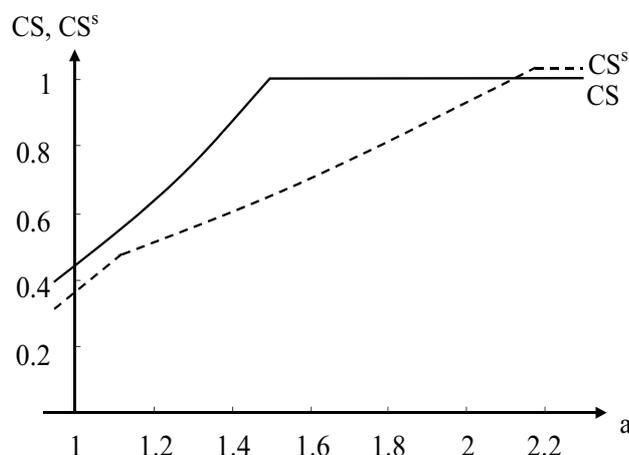


Figure 4.7: Consumer surplus with and without subcontracting

off and deviate. Subcontracting may be a means to distribute part of total profits in such a way, that no firm would wish to deviate. The problem is that subcontracting changes competition and total profits as well. It is not clear to what degree profits will be reduced by the competitive effects of subcontracting. Therefore profits and welfare for outcome (n_s, o_s) with subcontracting will be calculated.

Firms again noncooperatively choose quantities and the subcontracting price. Profits (n_s, o_s) are determined as follows. Firm 1 produces each product x and y in one plant and firm 2 produces product y in one plant. In the third stage optimal quantities are determined by

$$\begin{aligned}
 n_s(x_1, y_1, s, y_2 | t) &= \max_{x_1, y_1} (a - x_1 - s)x_1 + ts + (a - y_1 - y_2)y_1 - F_n \\
 &\quad s.t. \quad x_1 + s \leq K, \quad y_1 \leq K \\
 o_s(x_1, y_1, s, y_2 | t) &= \max_{s, y_2} (a - x_1 - s)s - ts + (a - y_1 - y_2)y_2 \\
 &\quad s.t. \quad y_2 \leq K
 \end{aligned} \tag{4.3}$$

In the second stage firm 1 chooses the subcontracting price t .

$$\begin{aligned}
n_s(t) &= \max_t (a - x_1^* - s^*)x_1^* + ts^* + (a - y_1^* - y_2^*)y_1^* - F_w \\
s.t. &\quad \begin{cases} o_s(t) \geq k & \text{if } a_1 < a < a_2 \\ o_s(t) \geq p & \text{if } a_2 \leq a \end{cases} \quad (4.4)
\end{aligned}$$

$$\text{with } o_s(t) = (a - x_1^* - s^*)s^* - ts^* + (a - y_1^* - y_2^*)y_2^*$$

Comparing profits with and without subcontracting leads to the result that firms would only share capacities through subcontracting at high demand levels, were firms would have increased capacities anyway. Consumers would be worse off with subcontracting. At low demand levels, the Pareto improving outcome is not a noncooperative Nash-equilibrium. This is due to the fact that the subcontracting mechanism changes competition and lowers total profits in such a way that firm 1 can not redistribute profit to firm 2 without being worse off itself. Firm 1 will not participate in subcontracting.

Proposition 11 (*Capacity decisions with subcontracting*)

With subcontracting there is no solution for sharing capacities where firms noncooperatively subcontract and consumer surplus increases. For $a_1 \leq a < a_2$ consumers would benefit but firms are worse off, for $a \geq a_2$ firms benefit but consumers are worse off.

Proof. See appendix B.2, the profit functions in figure 4.8 and consumer surplus in figure 4.13.

Figure 4.8 shows firms' profits with and without subcontracting. The comparison is of particular interest for demand levels at which non-subcontracting firms would be capacity constrained but not yet willing to increase capacity ($1.5 < a < a_2 \approx 2$). Firm 2's profit with subcontracting o_s is equal to its profit without subcontracting in figure 4.1. Firm 1's profit without subcontracting n_s has to be at least as high in order for firm 1 to participate in subcontracting. This is only the case for demand levels $a \geq a_2$.

Firms' output and industry output with subcontracting are shown in figure 4.9 and figure 4.10.

Again, there are critical demand levels at which optimal output and prices clearly change. At demand levels $a > 1.56$ firm 1 starts getting capacity constrained when subcontracting. Total quantity of product x, $x_1 + s$, is then fixed and equal to the capacity of one plant. An increase of quantity s subcontracted (sold) to firm 2 leads to a decrease in firm 1's quantity x_1

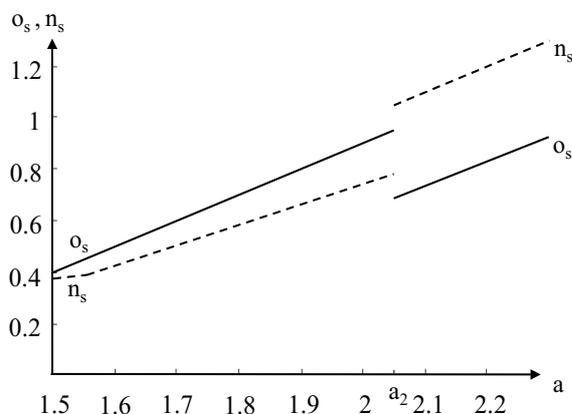


Figure 4.8: Profits with and without subcontracting

sold directly on the market. At demand levels $a > 2.04$, in the reference case without subcontracting, both firms would increase capacities and have lower profits. Thus, for the case with subcontracting, firm 1 can more easily guarantee firm 2 this lower profit. The subcontracting price t jumps to a higher level, see figure 4.11, and the subcontracted quantity s jumps to a lower level, see figure 4.9

Industry output with subcontracting is shown in figure 4.10. None of the two firms is capacity constrained at demand levels $1.5 < a < 1.56$. Industry output Y^s is the (unconstrained) Cournot quantity which increases with demand. Industry output X^s is slightly lower because firm 1 internalizes the subcontracting effect that it will have to compete directly against the subcontracted quantity it sells to its rival. For demand levels $a > 1.56$ firm 1 is capacity constrained only for product x and not for product y . Industry output of product x is equal to capacity while industry output of product y is equal to the (unconstrained) Cournot level. In contrast, if firms do not subcontract, industry output for each product would be equal to capacity. The positive capacity effect for firms and consumers derives solely from the increase in output of product y .

Prices are illustrated in the figures 4.11 and 4.6.

Figure 4.11 shows the prices with subcontracting for product x and product y , P_x^s and P_y^s , and the subcontracting price t . The price for product x starts rising strongly once firm 1 starts getting capacity constrained

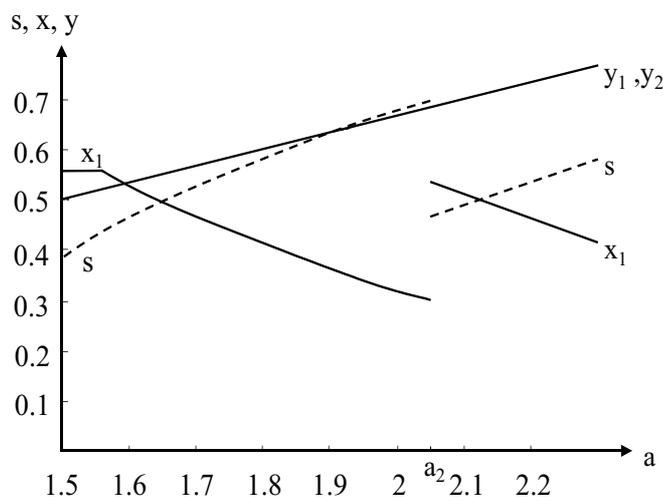


Figure 4.9: Firms' output with subcontracting

($a > 1.56$). The subcontracting price t jumps at demand a_2 , where non-subcontracting firms increase capacity. The price of product y is the (unconstrained) Cournot price. Figure 4.6 shows the prices without subcontracting of products x and y , P_x and P_y ($P_x = P_y$). The price is equal to the capacity constrained price at demand levels $a < a_2$, otherwise it is equal to the (unconstrained) Cournot price. Basically, subcontracting leads to a lower (or equal) price of product y and a higher (or equal) price of product x .

Consumer surplus with and without subcontracting is compared in figure 4.13. Consumer surplus with subcontracting is higher for demand levels $a < a_2$ because the capacity effect of an additional plant leads to a higher industry output of product y . The exception is a small demand region, where the negative subcontracting effect of product x dominates the positive capacity effect of product y ($1.5 < a < 1.56$).

4.1.4 Welfare

The welfare effects of subcontracting depend on the trade-off between efficiency gains and potentially collusive behaviour due to the change in competition. Three competitive effects influencing output shall be distinguished: a specialization, a capacity and a subcontracting effect. Their influence on firms and consumers when compared to the situation without subcontracting

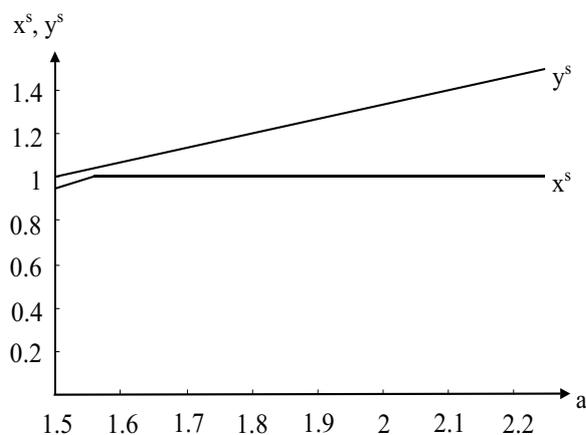


Figure 4.10: Industry output with subcontracting

is shown in the following table:

	Firm 1	Firm 2	Consumers
Fixed costs savings	(-)	+	
Specialization effect	+	-	-
Capacity effect	+	+	+
Subcontracting effect	-	+	-

A firm can save fixed costs if it engages in subcontracting instead of producing a second product or plant. The specialization effect occurs when one firm stops producing a product. The other firm would potentially turn into a monopolist and consumers would be worse off. The opposite of specialization would be an increase in product variety, that is when one firm starts producing a second product. The capacity effect is the increase of output which occurs when a capacity constraint of one or both products no longer holds. The subcontracting effect reduces output and profits of the selling firm. The buying firm is always better off because it can buy at a subcontracting price which is below the market price. Consumers are worse off, because if both firms would instead independently produce and sell the product, industry output would be higher.

The welfare effects of subcontracting with product decisions are shown in figure 4.14.

Proposition 12 (*Welfare and product decisions*)

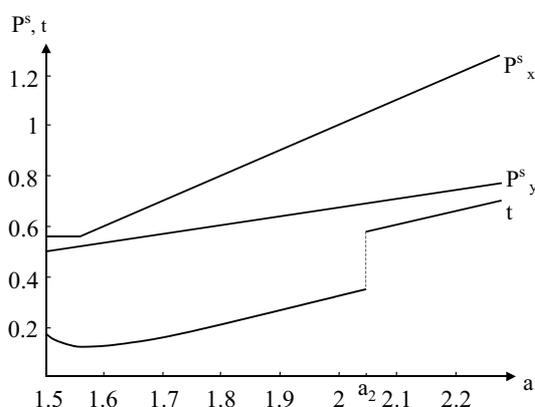


Figure 4.11: Prices with subcontracting and subcontracting price t

Welfare increases with subcontracting at demand levels $a_1 \leq a < 1.3$.

Proof. See above and appendix B.2.

Remark 3 *The possibility of subcontracting does not lead firms to offer the full range of products already at lower demand levels ($a < a_1$).*

The effects of subcontracting on product decisions are relevant and shown for demand levels where there are no capacity effects. At low demand levels ($a < a_1 = 0.94$), each firm could increase product variety through subcontracting, but firm 1 has no incentive to participate. At higher demand levels ($a \geq a_1$), without subcontracting both firms produce both products. With subcontracting firm 2 specializes and saves fixed costs and the subcontracting effect decreases. Firm 1 does not have higher fixed costs and specialization now outweighs the lower (negative) subcontracting effect. Consumers are worse off because there are no capacity effects, see table above. The results might change, if the positive effect of an increase in product variety were higher, for example if products were complements, or if capacity effects would be relevant.

The welfare effects of subcontracting with capacity decisions are shown in figure 4.15.

Proposition 13 (*Welfare and capacity decisions*)

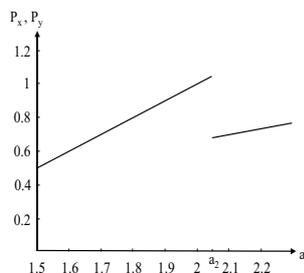


Figure 4.12: Prices without subcontracting

Welfare does not increase when firms subcontract ($a > a_2$). Welfare would be higher at demand levels $1.7 < a < a_2 \approx 2$, but firms do not noncollusively subcontract.

Proof. See above and appendix B.2.

The effects are shown in the table above. The capacity effect is relevant at demand levels, where firms are capacity constrained if they do not subcontract ($1.5 < a < a_2 \approx 2$). Then the positive capacity effect of subcontracting would for almost all demand levels increase welfare above the welfare level without subcontracting. But for firm 1 the capacity effect would not be strong enough to outweigh the higher fixed costs of capacity expansion and the negative subcontracting effect. At these demand levels firm 1 would not subcontract.

4.1.5 Conclusion

This chapter analyzed how subcontracting between rival firms influences product and capacity competition as well as welfare when firms face lumpy investments.

Subcontracting presents a trade-off between allocating production more efficiently by saving fixed costs of increasing product variety or capacity and potentially collusive behaviour due to specialisation, capacity and subcontracting effects. If subcontracting is not allowed, specialization would of-

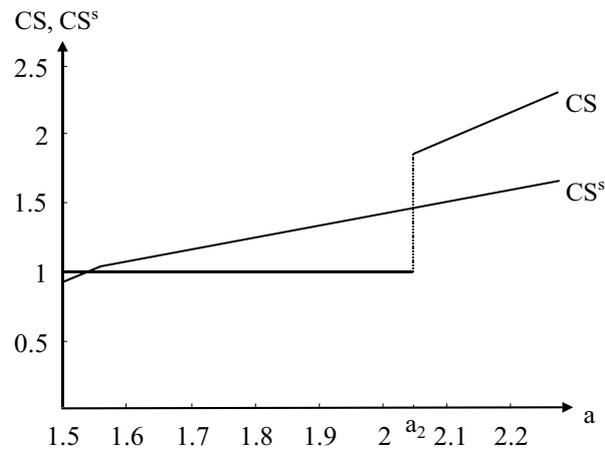


Figure 4.13: Consumer surplus with and without subcontracting

ten be Pareto dominant but no Nash-equilibrium. With subcontracting they could be equilibria. But when firms noncollusively subcontract consumers are worse off, even if welfare rises. Either firms or consumers benefit but never both. Symmetric non-convexity of costs changes traditional results. Subcontracting with independent products has a collusive character.

The results were derived in general, even if they were illustrated with examples. The results crucially depend on whether firms have excess capacity or a binding capacity constraint. This is determined by the relationship of demand to the technologically given plant capacity. Normalizing plant capacity to a fixed value and varying the demand level produces all possible ratios of demand to plant capacity. Furthermore, the fixed costs of switching the product line on a plant or increasing capacity by a new plant influenced firms' profits. Choosing values in the example influenced the absolute level of demand at which a firm would switch from one regime to another, for example the demand level upto which subcontracting is more profitable than not subcontracting. Choosing pathologically high fixed costs would of course change the economic interpretation, such that producing a second product or subcontracting would never be profitable. But for reasonable fixed costs the qualitative results would not change for different levels of fixed costs. For example, consumer surplus or the basic feature, that subcontracting is beneficial either for firms or consumers, remain the same.

The model is based on assumptions which are unfavourable for subcon-

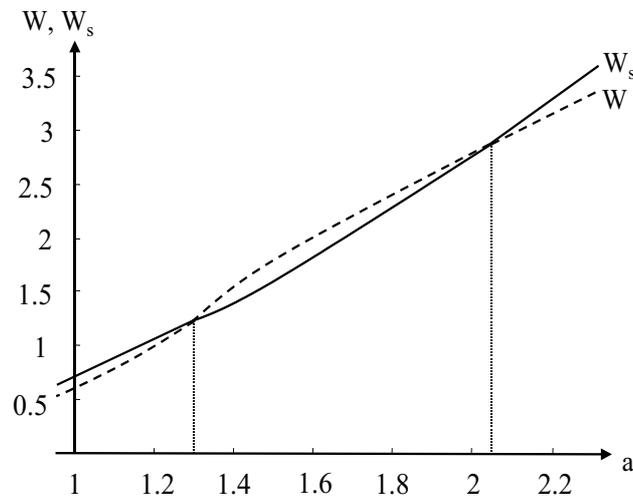


Figure 4.14: Welfare for product decisions with and without subcontracting

tracting. This concerns the set-up of the model and the (dis-)economies of scope on the production and on the demand side.

In the set-up of the model with ex-ante subcontracting, firms first subcontract and then simultaneously choose all outputs in the last stage. Changing the game would change the results. For example, with ex-post subcontracting, one firm would first have to commit to the subcontracted quantity. Similarly, in Kamien, Li and Samet (1989), either the winner or loser of an auction is a Stackelberg leader who sets the terms of the subcontract. Here, the set-up is chosen differently, because apart from the fact that both firms can access the market on their own, comparing a non-subcontracting Cournot game with a subcontracting Stackelberg game would change the results in favour of subcontracting already due to the fact, that a Stackelberg output is always higher than a Cournot output. Instead, we compare two Cournot games with and without subcontracting.

The economies of scope on the production side consist of fixed cost savings. Firms do not have asymmetric convex costs, the driving force for more efficient production and beneficial subcontracting in the literature. If marginal costs would decrease, for example due to economies of scale of learning, subcontracting would be more beneficial for firms and consumers.

Finally, economies of scope on the demand side are not considered as products are independent and benefit is separable. This would not be the case

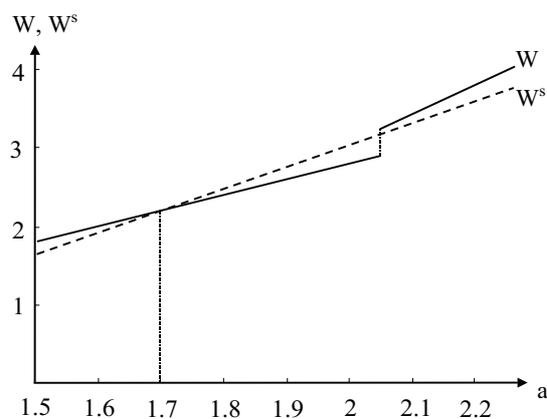


Figure 4.15: Welfare for capacity decisions with and without subcontracting

if demand is generated by a firm which needs to combine two intermediate inputs to a final product or if consumers' utility would depend on whether products are complements or substitutes. Complementary products would tend to enhance the welfare effects of subcontracting.

Two possible extensions seem interesting. First, complementarities on the demand side seem to be relevant in many markets. Secondly, horizontal subcontracting might be similar to network competition. If one thinks of a firm as offering two products on a market, one which it sells directly and a second product (the "last mile" in telecommunication) which it sells to a rival firm, then regulating the price of the second product might be comparable to regulating a subcontracting price.

The model is tailored to characteristics of the flat glass market. It explains the phenomenon that firms are least interested in subcontracting when they start getting capacity constrained and are most interested if they would otherwise have high excess capacities. Specialization overseen and enforced by anti-trust authorities would at least in theory be beneficial in states of high excess capacities. Relying on a market solution such as subcontracting would not work. Basically, subcontracting tends to have a collusive character. In particular, if consumer surplus is the main criterion for competition policy then subcontracting should not be allowed. If welfare is the main criterion, competition policy should, for a wide range of demand levels, allow for subcontracting.

Chapter 5

Exchange agreements between competitors with different efficiency levels

5.1 Introduction

Firms within the same industry often differ with respect to their efficiency and performance and sometimes firms with different efficiency levels enter exchange agreements. What are the competitive effects of exchange agreements between competitors? How does the trade-off between potentially collusive effects, e.g. due to a division of markets, and efficiency effects look like and how is welfare affected? What policy conclusions do the results lead to?

In an exchange agreement competitors determine an exchange ratio for products to be exchanged. Then quantities of the products are exchanged in this proportion without any monetary transfers.

The exchanged products can be inputs, which are then used by vertically integrated companies to produce outputs. They may also be outputs, which a company then sells under its own name, without informing the consumers/firms, that it did not produce all of the outputs itself (see figure 5.1).

There is only a small literature dealing with exchange agreements and horizontal subcontracting. In Holt and Scheffman (1988) an exchange is a simultaneous buy/sell arrangement generally involving equal amounts of each commodity. In the exchange agreement the ratio of physical units of the commodities is fixed. In addition Holt and Scheffman require the use

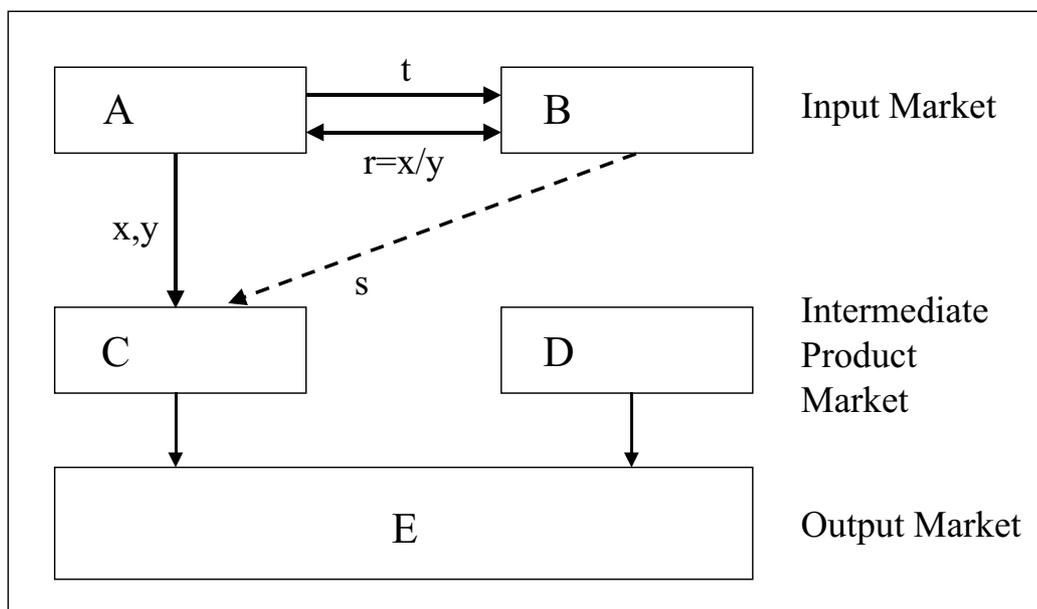


Figure 5.1: Market structure

of a monetary adjustment per unit of exchange to compensate for value differentials. They then look at two vertically integrated producers each being a monopolist in the production of one input. Furthermore both inputs are needed in fixed proportions to produce a homogeneous final product. So each producer is forced to buy from the other producer and the exchanged quantity determines how much of the final product can be produced by the company. Exchanges are then similar to vertical integration, because firms trade the inputs at marginal costs instead of paying input-price markups. This is reminiscent of the double marginalization problem, the successive mark-ups (marginalization) due to vertical externalities, where firms would be better off with vertical integration, see Tirole (1988). But as firms do not want to produce more than the monopoly output and both firms need the other firms input in a fixed proportion the monopoly output can be sustained through the exchange. So input exchange agreements can be anticompetitive, when there is market power in the input market. This need not hold if each firm could produce both products.

This chapter will allow for companies to consider producing all products on their own and inputs do not have to be used in fixed proportions. Firms

can produce and compete with two products and there is competition on the output market.

In the literature on horizontal subcontracting by Kamien, Li and Samet (1989) and Spiegel (1993) companies commit to subcontracted quantities instead of using an exchange mechanism and a fixed exchange ratio. Instead, subcontracted quantities are bought from the competitor at a transfer price.

Other parts of the literature look at production and/or capacity sharing arrangements between competitors which work via other forms of coordination than exchange agreements. These include production joint ventures (mechanism: financial and control arrangements), independent production joint ventures (dedicated capacity), subcontracting (quantity and transfer prices), cross-supplies (market prices and commitment to quantities) and resalable capacity considerations.

In the international trade literature intra-industry trade in identical commodities may be due to having two countries being in a Cournot market each and so having one country producing for the other country and vice versa. In Brander (1981) each country ships the identical product to the other country as long as the marginal transportation costs are not too high. Bernhofen and Unterberdoerster (1997) find that asymmetries in cost efficiency, market size and firm concentration reduce intra-industry trade. Leahy and Montagna (1997) look at the question whether government should reduce firm heterogeneity in an industry by helping the weaker more than the stronger firm. Their analysis suggests favouring more efficient firms. In these papers intra-industry trade does not refer to the case where firms exchange products directly before competing (this could be called inter-firm trade in an industry).

In this chapter firms have different efficiency levels. This could be due to different reasons, e.g. because of different capacity constraints or costs associated with the change of product lines. If a firm faces a capacity constraint (e.g. a technologically determined plant size) and faces set-up costs for producing a second product, it could allocate the set-up costs solely to the new product. A firm would then have to decide whether to produce only the low-cost product and possibly enter an exchange agreement with a competitor for the high-cost product or produce both products on its own.

In a three stage game, two firms are able to produce two products. Each firm has a cost advantage with one of the products. If there is an exchange agreement they first decide on an exchange ratio. They then determine the exchanged quantity. Each company states the quantity it wishes to exchange

given the exchange ratio, and the lower value determines the exchanged quantity. Finally, they compete in quantities.

With an exchange agreement firms can lower their costs. But firms do not always prefer low cost structures. As a benchmark case a low cost structure will be the case of efficient production where all products are produced with the lowest possible production costs. Low cost structures can be achieved through a production joint venture (PJV) in which production is overseen by an independent management company set up by the two competing firms. The two companies can place orders for output at marginal costs and then compete at the marketing stage. Gale (1994) describes such an agreement between two aluminium companies Alcan and Arco where the rolling mill is jointly owned and operated by an independent management company. After a purchase of Alcan had been challenged by the U.S. Department of Justice firms accepted this consent decree. Since then the European Commission has continued to keep a close watch on production joint ventures but started to approve PJVs on similar terms, e.g. a PJV between chemical producers Exxon Chemical Polymer and Shell Chimie SA for the production of linear low-density polyethylene in France (see Milmo 1994).

Firms will always prefer exchange to no exchange while consumers are indifferent. The result depends on the fact that firms completely take into account the strategic effect of having to compete against exchanged quantities. Exchanges are welfare enhancing but do not reach the welfare level achieved by firms with low-cost structures.

The outline of this chapter is as follows. Section (5.2) introduces the model and section (5.3) compares two no exchange equilibria with different cost structures. Section (5.4) solves for equilibria of an exchange agreement followed in section (5.5) by welfare comparisons. Section (5.6) concludes with a discussion and draws some conclusions for further research and economic policy.

5.2 The model

Consider an industry consisting of two firms, 1 and 2, and two markets, the market for product x and the market for product y . Each firm can produce either one or both products but each firm has a cost advantage in one of the product lines.

The two firms can either enter an exchange agreement or compete without

an exchange agreement. If the firms enter an exchange agreement they play the following three-stage duopoly game:

Stage 1: Firms agree upon an exchange ratio $r = x/y$.

Stage 2: Firms decide how much they would wish to exchange. The exchanged quantity e^* is determined as the minimum of the desired quantities, $e^* = \min\{ry, x\}$.

Stage 3: Firms simultaneously and independently choose outputs. Each firm decides how much to produce of its low cost product and, if at all, how much to produce of its high cost product.

If firms do not enter an exchange agreement, firms only play stage 3.

The assumptions concerning the cost structure and the demand side are as follows:

Each firm has a cost advantage in producing one of the products: firm 1 for product x and firm 2 for product y . The marginal cost of the low-cost product is c_1 and for the high-cost product $c_2, c_2 \geq c_1$. Note that the subscripts of marginal costs only refer to the cost level and not to a firm. Firm 1 (firm 2) can produce product x (product y) with low costs c_1 (c_2) and product y with high costs c_2 (c_1). There are no fixed costs and firms have complete information about their rival's costs. The cost function for firm i for producing products x and y is

$$C_i(x, y) = c_i x + c_j y \quad i \neq j, i = 1, 2 \quad (5.1)$$

Firms face the linear demand system

$$\begin{aligned} P_x(x_1, x_2) &= 1 - X = 1 - x_1 - x_2 \\ P_y(y_1, y_2) &= 1 - Y = 1 - y_1 - y_2 \end{aligned} \quad (5.2)$$

with x_i, y_i as total sales of firm i of product x and product y . The total quantity X is the sum of the quantities of good x the two firms sell on the market, $X = x_1 + x_2$. The total sales of a product of a firm depend on how much the firm produces and exchanges of this product (see figure 5.2).

More specifically for product x

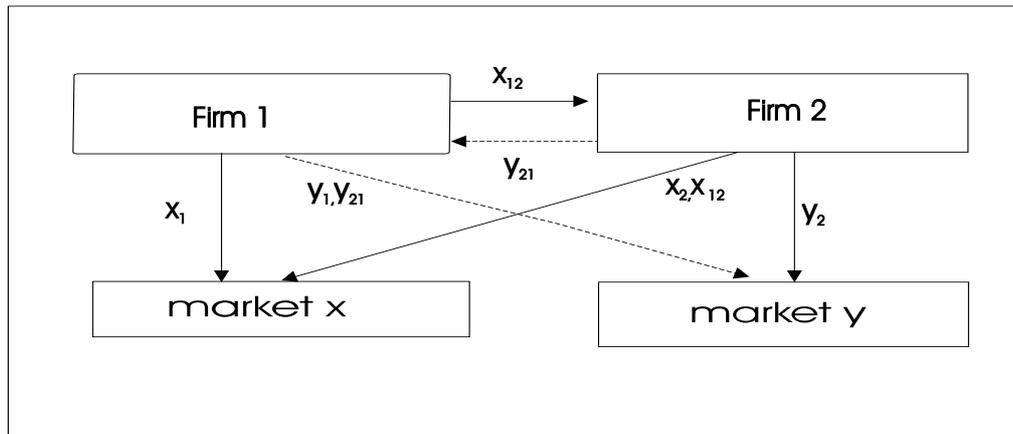


Figure 5.2: Market structure with exchange agreements

$$X = x_1 + x_2 \quad \text{with} \quad \begin{aligned} x_1 &= x'_1 \\ x_2 &= \begin{cases} x_2 & \text{if } x_2 \leq x_{12} \\ x'_2 + x_{12} & \text{if } x_2 > x_{12} \end{cases} \\ x_i &\text{ total sales of firm } i, i = 1, 2 \\ x'_i &\text{ quantity } x \text{ produced by firm } i \\ x_{12} &\text{ quantity } x \text{ produced by firm 1 and} \\ &\text{exchanged to firm 2} \end{aligned}$$

Firm 1 has an advantage in producing product x and will produce all of the amount it sells on its own, $x_1 = x'_1$. Firm 2 incurs high costs when producing product x . It is interested in exchanging product x in return for product y , that is firm 2 wants to receive quantity x_{12} from firm 1. The exchanged quantities are determined on stage 2 of the game and are sunk on stage 3 where firms choose total sales. If firm 2 wants to sell less than it exchanged for, it doesn't have to produce anything of product x on its own. Instead it uses as much of the exchanged quantity it wants to sell, $x_2 \leq x_{12}$. Firm 2 will start producing product x on its own if it wants to sell more than it exchanged for, that is $x_2 = x'_2 + x_{12}$ if $x_2 > x_{12}$. Similar considerations hold for firm 1:

$$Y = y_1 + y_2 \quad \text{with} \quad y_1 = y'_1 \quad \text{and} \quad y_2 = \begin{cases} y_2 & \text{if } y_2 \leq y_{21} \\ y'_2 + y_{21} & \text{if } y_2 > y_{21} \end{cases}$$

Quantities with two subscripts denote exchanged quantities, with x_{ij} as firm i exchanging product x to firm j . As firms only trade their low cost products for high cost products there are only two possibilities for exchanged quantities, namely x_{12} and y_{21} . Firm 1 has an advantage in producing product x . It will be interested in delivering quantity x_{12} to firm 2 and in getting product y_{21} from firm 2 in exchange. The actually exchanged quantities are determined by $e^* = \min\{ry_{21}, x_{12}\}$.

The solution concept is that of a subgame perfect Nash equilibrium. A strategy for firm 1 is a decision plan $s_1 = \{\hat{r}_1, \hat{y}_{21}(r), \hat{x}_1(e^*, r), \hat{y}_1(e^*, r)\}$ where \hat{r} , \hat{x} and \hat{y} indicate the best exchange and output decisions conditional on every possible exchange and output choice of firm 2. Similar considerations hold for firm 2. Profit functions depend on exchange and quantity choices and the strategy profile $\{s_1, s_2\} = \{\hat{r}_1, \hat{x}_1, \hat{y}_1, \hat{y}_{21}, \hat{r}_2, \hat{x}_2, \hat{y}_2, \hat{x}_{12}\}$ determines the outcomes $r, x_i, y_i, x_{21}, y_{12}$. Solving the profit functions with these outcomes yield the (reduced form) payoff functions.

As firms are symmetric and calculations similar for both firms, they will only be done for firm 1 unless firm 2 has to be considered explicitly.

5.3 No exchange agreement equilibria

In order to separate efficiency effects from strategic effects resulting from the specific exchange mechanism two situations will be compared. In the first case there is no exchange agreement and both firms have asymmetric costs, that is low unit costs for one product and high unit costs for the second product. For the second case it will be assumed that both firms could produce both products at low costs e.g. through a production joint venture (PJV) where each firm can buy the products at marginal costs from an independent management company¹. One could also imagine that each firm trades its low cost product in exchange for the product it would otherwise have to produce at high costs. The low-cost structure (PJV) will be the benchmark case representing the highest possible production efficiency and social welfare. How and if this could be achieved through an exchange mechanism will not yet be looked at in order to exclude strategic effects of the exchange mechanism.

¹In the model by Gale (1994) capacity is determined by firms' "dedicated capacity" and firms are, as noted in the consent decree, subject to a "use-or-lose" provision: "Each party to the joint venture may utilize any unused portion of the other party's capacity by assuming the variable costs, but not the fixed costs, attributable to the added production".

The first result is that firms will not always prefer the low-cost structure. If the costs are sufficiently far apart it will be more profitable for a firm to be almost an monopolist on one market and forego profit on the second market. The advantage of cost heterogeneity will then be higher than the efficiency gains.

5.3.1 No exchange agreement with asymmetric costs

Firms make quantity decisions. Costs are asymmetric with $c_2 > c_1$ and without loss of generality assume $c_2 < 1$. Total demand is $X = x_1 + x_2, Y = y_1 + y_2$. The profit function of firm i is²

$$\pi_i^a(x_i, y_i) = P_x x_i + P_y y_i - c_i x_i - c_j y_i$$

Solving for quantities yields

$$x_1 = \begin{cases} \frac{1+c_2-2c_1}{3} & \text{if } c_2 \leq \frac{1+c_1}{2} \\ \frac{1-c_1}{2} & \text{if } c_2 \geq \frac{1+c_1}{2} \end{cases} \quad (5.3)$$

$$x_2 = \begin{cases} \frac{1+c_1-2c_2}{3} & \text{if } c_2 \leq \frac{1+c_1}{2} \\ 0 & \text{if } c_2 \geq \frac{1+c_1}{2} \end{cases}$$

and $y_j = x_i, i \neq j; i, j = 1, 2$. Figure (5.3) illustrates the duopoly and monopoly regions for product x.

If both firms enter both markets total demand is $X^a = Y^a = \frac{2-c_1-c_2}{3}$ and market price $p^a = \frac{1+c_1+c_2}{3}$. Inserting the duopoly solutions gives the reduced form payoff function, the profit for firm i is

$$\pi_i^a(c_1, c_2) = \frac{(1+c_2-2c_1)^2}{9} + \frac{(1+c_1-2c_2)^2}{9}. \quad (5.4)$$

Within the duopoly region both firms will produce both products. Otherwise at least one firm would enter only one or no market. This firm would then have an incentive to deviate and earn a higher payoff by entering the other firm's monopoly market. So these outcomes will be dominated by the outcome in which both firms enter both markets. It is similar to a prisoner's dilemma where both firms would be better off being a monopolist in one

²Superscripts will be a for asymmetric costs, s for symmetric costs and e for the exchange case.

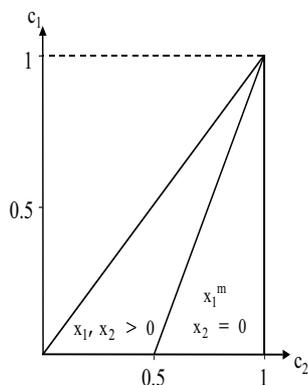


Figure 5.3: Firms' quantities with no exchange agreement and asymmetric costs

market but each firm has an incentive to deviate and enter the other firms market. It would then not only earn its monopoly profit but in addition a Cournot profit.

If costs are not too high both firms enter both markets and equilibrium quantities are as in (5.3).

5.3.2 No exchange agreement with symmetric low costs: production joint venture

Now we look at the same duopoly region with symmetric low costs, $c_1 = c_2$. Then the equilibrium will yield that both firms enter both markets and the solution is $x_1 = y_1 = \frac{1-c_1}{3}$ with $X^s = Y^s = \frac{2(1-c_1)}{3}$ and market price $p^s = \frac{1+2c_1}{3}$. Profits for firm i are

$$\pi_i^s(c_1, c_1) = \frac{2(1-c_1)^2}{9} \quad (5.5)$$

Proposition 14 *Firms prefer competing at low costs if $\Delta\pi_1 = \frac{1}{9}(c_2 - c_1)(2 - 5c_2 + 3c_1) > 0$. Consumers always prefer lower costs.*

Proof: Straightforward calculation and factorization of $\Delta\pi_1 = \pi_1^s - \pi_1^a$ yield above result. Consumers are better off when both firms have symmetric low costs for both products rather than asymmetrically low unit costs for one product and high unit costs for the second product, because in the symmetric case total quantity is higher, $X^s > X^a$, and market price is lower, $p^s < p^a$. ■

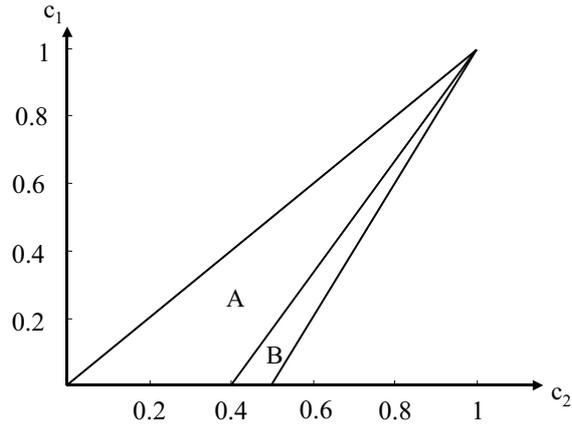


Figure 5.4: Firms' quantities with no exchange agreement and symmetric costs

In figure 5.4 regions A and B are the feasible set of (c_1, c_2) combinations in which the produced quantities are not negative. In region A $\Delta\pi_1 > 0$ and firms prefer the low-cost structure, that is the welfare maximizing case of efficient production. In region B firms are better off competing with asymmetric costs.

This result means that firms do not always prefer to compete with symmetric low costs in two markets but would sometimes prefer to compete with asymmetric costs in both markets despite the fact that the sum of unit costs is higher. This is due to two countervailing effects. There is a trade-off between more efficiency due to lower costs and more specialization and market power due to focusing on one market and cost heterogeneity. The efficiency effect makes firms want to have as low costs as possible. On the other hand firms prefer to be different in costs and thereby increase specialization and market power in one market.

The two effects are illustrated in an example.

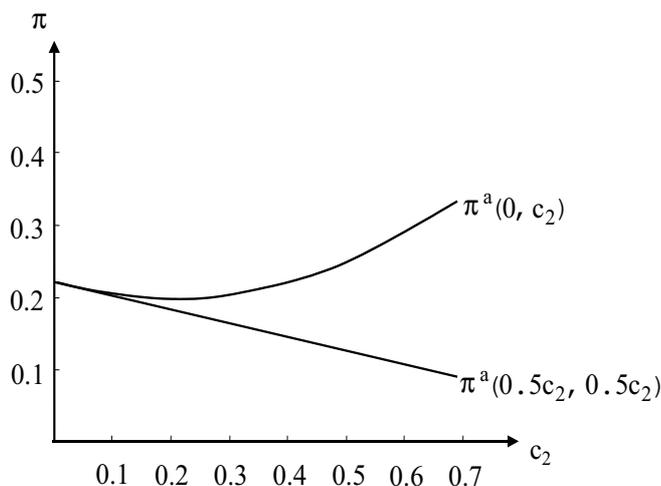


Figure 5.5: Firms' profits for symmetric and asymmetric costs

Assume $c_1 = 0$, $c_2 > c_1$. Then with an increase in c_2 and thereby an increase in asymmetry in both markets the profit for one firm is $\pi^a(0, c_2)$. If the sum of the unit costs were split equally profit would be $\pi^s(\frac{1}{2}c_2, \frac{1}{2}c_2)$. Comparing the profits in figure 5.5 shows that asymmetry will always be preferred to symmetry.

The profit for symmetrically low costs is $\pi^s(0, 0)$. Now the interesting comparison is between the efficient profit $\pi^s(0, 0)$ and the asymmetric profit $\pi^s(0, c_2)$, see figure 5.6. The shaded area shows where efficiency gains prevail. At the intersection $c_2 = 0.4$ the advantage of asymmetry starts to outweigh the efficiency gains. This point corresponds to the most outward c_2 of region A in figure 5.4 where $c_1 = 0$ and $c_2 = 0.4$. At the maximal $c_2 = 0.5$ each firm is a monopolist in one market.

5.4 Exchange agreement equilibria

5.4.1 Stage 3

At stage 3 the exchange ratio $r = x_{12}/y_{21}$ and the exchanged quantity $e^* = \min\{ry_{21}, x_{12}\}$ are given. The demand system is

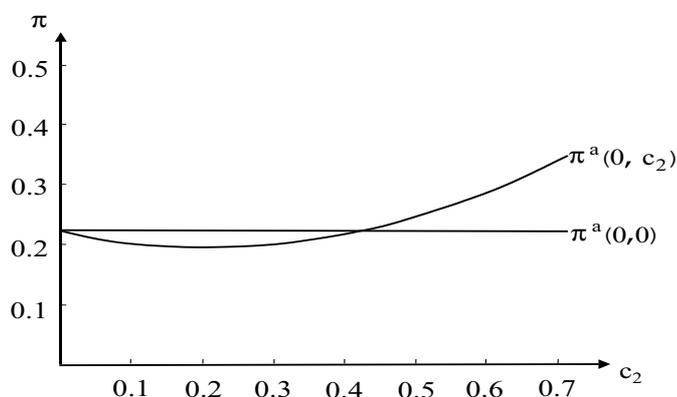


Figure 5.6: Firms' efficient and asymmetric profits

$$\begin{aligned} P_x(x_1, x_2) &= 1 - x_1 - x_2 \\ P_y(y_1, y_2) &= 1 - y_1 - y_2 \end{aligned} \quad (5.6)$$

The profit functions are

$$\pi_1(x_1, y_1 \mid r, e) = \begin{cases} P_x x_1 - c_1 x_1 + P_y y_1 & \text{if } 0 \leq y_1 \leq \frac{e}{r} \\ P_x x_1 - c_1 x_1 + P_y y_1 - c_2(y_1 - \frac{e}{r}) & \text{if } \frac{e}{r} \leq y_1 \end{cases} \quad (5.7)$$

$$\pi_2(x_2, y_2 \mid r, e) = \begin{cases} P_x x_2 + P_y y_2 - c_1 y_2 & \text{if } 0 \leq x_2 \leq e \\ P_x x_2 - c_2(x_2 - e) + P_y y_2 - c_1 y_2 & \text{if } e \leq x_2 \end{cases} \quad (5.8)$$

The profit function of firm 1 has to distinguish two regions of total sales y_1 . If total sales y_1 are less than the exchanged quantities agreed upon, $y_1 \leq y_{21} = \frac{e}{r}$, marginal costs are zero because the costs on stage 2 for the exchanged quantities are sunk on stage 3. Only if firm 1 starts producing the additional amount $y_1 - \frac{e}{r}$ does it incur high costs c_2 . Figure 5.7 illustrates this shift of the reaction curve of firm 1 at point $\frac{e}{r}$. If firm 1 has higher total sales, $y_1 \geq \frac{e}{r}$, the inward reaction curve $y_1(y_2)$ with marginal costs c_2 is relevant. If firm 1 sells less than the exchanged quantities, $y_1 \leq \frac{e}{r}$, the outward reaction curve with zero marginal cost is relevant.

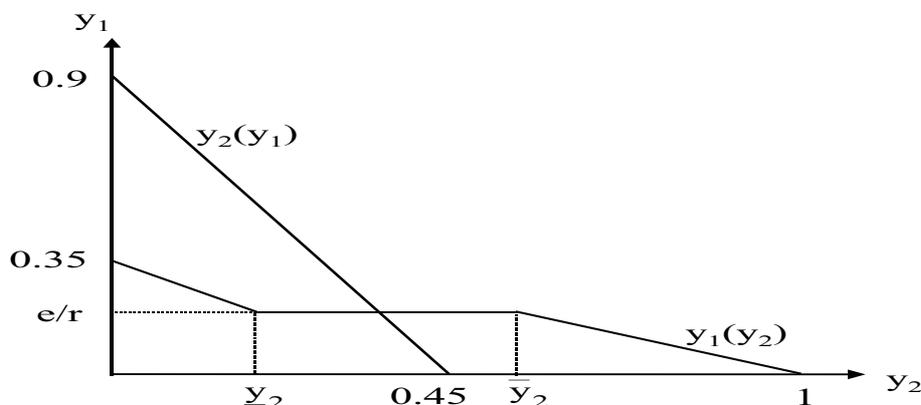


Figure 5.7: Sales of product y

Differentiating the profit functions (5.7) and (5.8) yields the reaction functions $y_1'(y_2) = \frac{1-y_2-c_2}{2}$, $y_1(y_2) = \frac{1-y_2}{2}$, $y_2(y_1) = \frac{1-y_1-c_1}{2}$ with $\underline{y}_2 = \frac{r-rc_2-2e}{r}$ and $\bar{y}_2 = \frac{r-2e}{r}$. When solving for y_1^* three regions have to be distinguished:

- A. $y_1 \leq \frac{e}{r}$ and $\underline{y}_2 \leq y_2$
- B. $y_1 = \frac{e}{r}$ and $\underline{y}_2 \leq y_2 \leq \bar{y}_2$
- C. $y_1 \geq \frac{e}{r}$ and $y_2 \leq \underline{y}_2$

In the cases A and B firm 1 does not produce anything of its high cost product y on its own. Similar considerations hold for firm 2. Taking into account these different regions the solution yields

$$(x_1^*, x_2^*) = \begin{cases} \left(\frac{1-2c_1}{3}, \frac{1+c_1}{3} \right) & \text{if } \frac{1+c_1}{3} \leq e \\ \left(\frac{1-c_1-e}{2}, e \right) & \text{if } \frac{1+c_1-2c_2}{3} \leq e \leq \frac{1+c_1}{3} \\ \left(\frac{1+c_2-2c_1}{3}, \frac{1+c_1-2c_2}{3} \right) & \text{if } 0 \leq e \leq \frac{1+c_1-2c_2}{3} \end{cases} \quad (5.9)$$

$$(y_1^*, y_2^*) = \begin{cases} \left(\frac{1+c_1}{3}, \frac{1-2c_1}{3} \right) & \text{if } r \frac{1+c_1}{3} \leq e \\ \left(\frac{e}{r}, \frac{r-rc_1-e}{2r} \right) & \text{if } r \frac{1+c_1-2c_2}{3} \leq e \leq r \frac{1+c_1}{3} \\ \left(\frac{1+c_1-2c_2}{3}, \frac{1+c_2-2c_1}{3} \right) & \text{if } 0 \leq e \leq r \frac{1+c_1-2c_2}{3} \end{cases} \quad (5.10)$$

5.4.2 Stage 2

On stage 2 firms decide for a given r how much they want to exchange and the lower of the desired quantities is then chosen. For every r an optimal e is determined.

The solutions (5.9) and (5.10) of stage 3 distinguish 9 regions of (e,r) combinations. This is shown in figure 5.8.

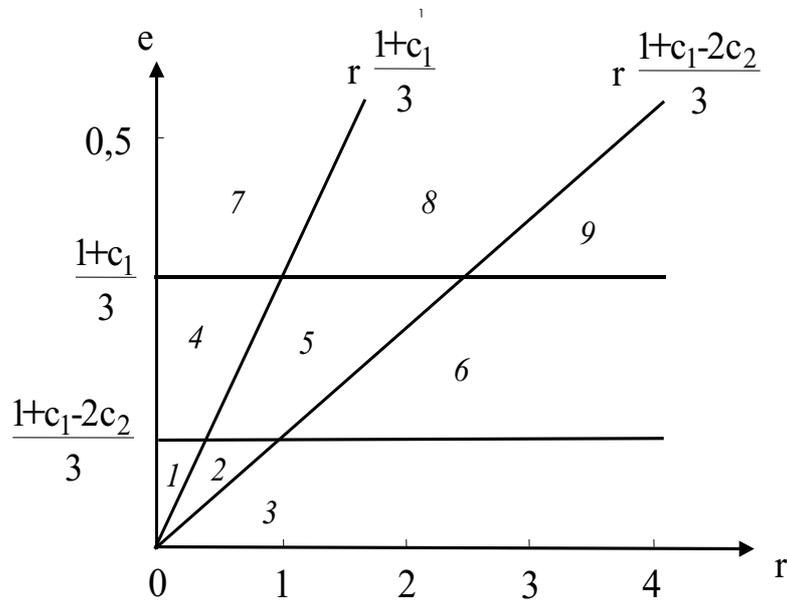


Figure 5.8: Equilibrium product variety

In region 3 both firms produce both products. In region 5 both firms only produce their low-cost product but sell both products. For both firms the quantity sold of the high-cost product is exactly the quantity exchanged for. In region 6 firm 1 produces both products and firm 2 produces only one product. The exchange ratio r is greater than 1 and favourable for firm 2. For 1 unit of x it only exchanges $1/r$ units of y . Firm 2 stops producing its high-cost product x at a point where firm 1 still produces both products. Similar considerations hold for region 2. for a detailed description of the regions see the table in the appendix.

For every given r the optimal e within each region has to be determined. Then comparing the reduced form payoff function for each of these e yields the optimal e^* for a given r . As boundaries are included in both of neighbouring regions no continuity problems arise. Due to symmetry reasons $r=1$ will be of special interest.

On stage 2 firm i has to decide how much quantity e it wants to exchange.

The profit functions are similar to the ones in (5.7) and (5.8), they now also include the cost of producing quantity e :

$$\pi_1(e | r) = \begin{cases} p_x x_1 - c_1 x_1 + p_y y_1 - c_1 e & \text{if } 0 \leq y_1 \leq \frac{e}{r} \\ p_x x_1 - c_1 x_1 + p_y y_1 - c_2(y_1 - \frac{e}{r}) - c_1 e & \text{if } \frac{e}{r} \leq y_1 \end{cases} \quad (5.11)$$

$$\pi_2(e | r) = \begin{cases} p_x x_2 + p_y y_2 - c_1 y_2 - c_1 \frac{e}{r} & \text{if } 0 \leq x_2 \leq e \\ p_x x_2 - c_2(x_2 - e) + p_y y_2 - c_1 y_2 - c_1 \frac{e}{r} & \text{if } e \leq x_2 \end{cases} \quad (5.12)$$

The reduced form payoff functions depend on what region in being considered. For $r=1$ regions 3,5, and 7 are relevant.

In region 3 both firms produce both products. Inserting the solutions $x_i = y_j = \frac{1+c_j-2c_i}{3}$ with $i \neq j; i, j = 1, 2$ in the profit functions and differentiating with regard to e leads to $\frac{\partial \pi_1}{\partial e} = \frac{c_2}{r} - c_1 \geq 0$ and $\frac{\partial \pi_2}{\partial e} = c_2 - \frac{c_1}{r} \geq 0$. Firm 1 wants to increase e as long as $r \leq \frac{c_2}{c_1}$. The cost for producing the exchanged quantities rc_1 has to be less than the opportunity cost c_2 of producing the high cost product itself. Firm 2 wants to increase e as long as $r \geq \frac{c_1}{c_2}$. In region 3 the optimal e is the minimum of the desired quantities. For $\frac{c_1}{c_2} \leq r \leq \frac{c_2}{c_1}$ this is the upper bound of region 3, otherwise $e=0$.

In region 5 similar considerations hold. The solutions $x_i(e), y_j(e)$ now depend on e . Inserting the solutions into the profit functions yield the reduced form payoff functions. Differentiation yields that $\frac{\partial \pi_1}{\partial e_1} \geq 0$ if $e_1 \geq \frac{r^2+r^2c_1-r-rc_1}{r^2-2}$ and for firm 2 that $\frac{\partial \pi_2}{\partial e_2} \geq 0$ if $e_2 \geq \frac{r+rc_1-r^2-r^2c_1}{1-2r^2}$. Furthermore, these e have to be within region 5 and cornersolutions to be checked. They would depend on r and the cost combinations (c_1, c_2) . For $r = 1$ both firms would want to reduce the exchanged quantities as much as possible, $\frac{\partial \pi_1}{\partial e} = \frac{\partial \pi_2}{\partial e} = -\frac{1}{2}e < 0$. This leads to the lower boundary and $e^* = \frac{1+c_1-2c_2}{3}$.

Similarly, in region 7 both firms want to reduce the exchanged quantities as much as possible.

Proposition 15 *In equilibrium for $r = 1$ both firms only produce their respective low-cost product, both firms sell both products and the exchanged quantity is $e^* = \frac{1+c_1-2c_2}{3}$.*

Proof. : See above. ■

5.4.3 Stage 1

On stage 1 the considerations done at stage 2 would have to be done for every possible r . As both firms are symmetric at the outset there is no reason to expect them to agree on a different r than $r=1$ (as a Nash bargaining solution). The equilibrium exchanged quantities would always be the same because one firm, the one with the disadvantageous r , would always announce a lower e than the other firm and thereby "veto" an unfavourable exchange quantity.

If one of the firms nevertheless had bargaining power it could propose a r different from 1. As long as the other firm would still be better off than without an exchange agreement the second firm would agree. The possible regions of r are outlined in the figure below. At the most outward points of $r = \frac{c_1}{c_2}$ and $r = \frac{c_2}{c_1}$ one firm would reap all the benefits from exchange. The exchange ratio r would determine the division of profits between the firms.

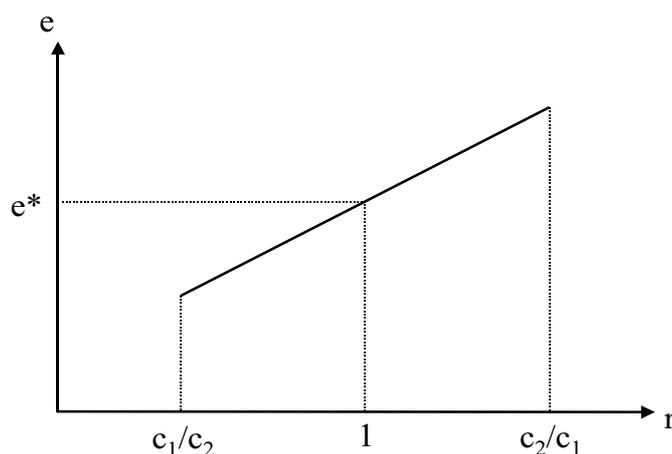


Figure 5.9: Equilibrium exchange quantity e^*

5.5 Welfare

There are three possible equilibria to compare.

The first question is whether exchange should take place. When there is no exchange agreement firms have asymmetric costs and in equilibrium

profits are $\pi_1^a(c_1, c_2) = \frac{(1+c_2-2c_1)^2}{9} + \frac{(1+c_1-2c_2)^2}{9}$ (see 5.4). With an exchange agreement firms produce nothing of the high cost products and exchange $e^* = \frac{1+c_1-2c_2}{3}$. Equilibrium profits are $\pi_1^e(e^*) = \frac{2-5c_1-2c_1^2+c_2+c_1c_2-c_2^2}{9}$. Firms will prefer exchange when $\Delta\pi_1 = \pi_1^e - \pi_1^a = \frac{(1+c_1-2c_2)(c_2-c_1)}{3} > 0$. This holds for the set of all feasible cost combinations where the produced quantity is still positive (see region A and B in figure 5.4). Consumers will be indifferent because firms exchange an amount of quantity e which is equal to the quantity they would otherwise produce with high costs. Total quantities and market price are the same for both situations, $X^e = X^a$ and $p^e = p^a$.

Proposition 16 *Exchange will always be better than no exchange. Firms are better off and consumers are indifferent. Welfare is higher with exchange.*

Proof: See above $\Delta\pi_1 > 0$ and $X^e = X^a$, $p^e = p^a$. ■

Firms reap all the gains from exchange because they exchange a quantity which corresponds to high costs while they in fact have low production costs. The reason why they calculate with higher costs is due to the strategic interaction. They know that they will eventually have to compete against their exchanged quantity on the output market. This reduces their profit and the opportunity cost of exchange increases.

Now another comparison is between the exchange agreement case and production joint venture case where both firms only have low costs and $\pi_1^s(c_1, c_1) = \frac{2(1-c_1)^2}{9}$ (see 5.5). Firms would prefer the specific exchange agreement if $\Delta\pi_1 = \pi_1^e - \pi_1^s = \frac{(1-c_1)(c_2-c_1)}{9} > 0$. This again will be the case for all cost combinations. On the other hand consumers are worse off for all cost combinations when comparing exchange to full trade because $X^s = \frac{2(1-c_1)}{3} > X^e = \frac{2-c_1c_2}{3}$ and $p^s = \frac{1+2c_1}{3} < p^e = \frac{1+c_1+c_2}{3}$. Welfare, defined as the sum of producer and consumer surplus, is higher for the case of a production joint venture.

Proposition 17 *Exchange is better for firms and worse for consumers when compared to the production joint venture case. Welfare is higher in the production joint venture case.*

Proof: See above. ■

5.6 Conclusion

The comparison shows that exchange will be better than no exchange although firms reap all the benefits. Nevertheless even with exchange the quantities will be lower than in the production joint venture (PJV) case. But this is not due to collusion supported through an exchange mechanism. The difference between exchange and a production joint venture lies in the different strategic considerations firms take into account when making their decisions. In the exchange case firms have complete information that they will eventually compete against their exchanged quantities and they can influence this quantity. This seems plausible in concentrated oligopolistic markets with long run relationships. In the PJV case firms assume there is a low cost structure but do not know (and can't prevent) what the competitor will do with the exchanged quantities. This seems more plausible in a market where concentration and transparency is low. Firms with high cost differences would prefer an exchange agreement, firms with small cost differences would prefer a PJV.

An extension would be to look at a different mode of competition. Basically there are two types of strategic interaction: firms compete in strategic substitutes or in strategic complements. In the first case this corresponds to Cournot competition with homogeneous products. The second case would be Bertrand competition with differentiated products.

Another aspect would be to link the asymmetric cost-structure directly to different capacities. Even for identical capacities different capacity constraints and opportunity costs could arise because e.g. one firm might partly possess monopoly power over a separate market or the plants have different breakdown or repair probabilities.

Empirically the hypothesis could be tested whether the exchanged quantity e^* really increases the smaller the cost difference are between firms in an industry. In parts, the literature on strategic trade policy and international trade look at similar questions. Intra-industry trade looks at two-way trade in similar products but does not capture the phenomenon of inter-firm trade and does not consider identically asymmetric cost structures. The traditional Grubel-Lloyd index as a measure of intra-industry trade in empirical studies is $\rho = 1 - \frac{|x_{12} - x_{21}|}{x_{12} + x_{21}}$, $\rho \in (0, 1)$ with higher values indicating higher intensity of bilateral trade. Values x_{ij} are the quantities firm i sells on market j and are equivalent to e in the above model. Now for any value of intra-industry trade created solely by inter-firm trade ρ would be 1 and otherwise

only change marginally. So to capture the effect of intra-industry trade in the form of inter-firm trade one approach could be to link the actually exchanged quantity e with cost asymmetries.

A conclusion with a policy recommendation could be as follows.

Basically a PJV and an exchange agreement are welfare enhancing. The PJV is even better than an exchange agreement but would not always be chosen voluntarily. In these cases allowing exchange agreements would increase welfare.

The anti-trust authorities should allow production joint ventures (low-cost structures) along the lines outlined above. They are unambiguously welfare increasing. But in the region of very asymmetric costs (region B) firms would not voluntarily enter a PJV. In these regions firms would still voluntarily enter an exchange agreement. Exchange agreements are not better in comparison to PJVs when cost asymmetry is low. If PJVs are not allowed an exchange agreement is a second-best solution. But preferably PJVs should always be allowed and exchange agreements should only be allowed in the case of strong cost heterogeneity.

Chapter 6

The European Flat Glass Market

In the subcontracting models, there has always been a direct reference to features of the flat glass market. In the subcontracting model concerning capacity and product variety decisions the technological and economic assumptions were described in detail. Nevertheless, it seems useful to give an overview of the flat glass market. In particular, it makes it easier to understand assumptions such that there are only a few major companies competing in strategic interaction, that due to technology only lumpy investments in capacity are possible and that production plants have a fixed capacity and high fixed costs. Adjustments in capacity can only occur incrementally. The crucial assumption of changes in demand, in particular a slowly growing demand, is one reason for capacity adjustments and a realistic feature of the EU glass production (see the federations data from June 1999). Due to high capacity per production plant ("tank") the overall number of plants is relatively small (see the figures for 1998 and the latest published geographical distribution from 1992). Following as an overview is the European Commissions description of the flat glass market when declaring a 50% stake by Pilkington in SIV, i.e. two major companies, compatible with the common market although concentration increased. One reason for this decision might have been the prospect of the entry of a Japanese firm. The assessment differs partially from the one given in the Italian flat glass decision, which the European Court overruled and which formed the basis of the horizontal subcontracting models. Information from federations and plant interviews are included.

6.1 The relevant product market and geographical reference market

Float glass is a separate product market and accounts for more than 90% of flat glass capacity. Other types of flat glass are manufactured using different production methods¹.

The float glass market can be analysed at two main levels.

Level 1: production of primary, raw float glass

Level 2: raw float glass is subject to further processing (more than one further downstream level)

6.1.1 Level 1

The relevant product market is raw or primary float glass. Raw float glass is a homogeneous commodity type product and has no substitute for applications at level 2. Some heterogeneity is introduced by body tinting and on-line coating².

The geographical reference market is the Community as a whole.

6.1.2 Level 2

Raw float glass has primarily two different uses: the general trade (80%), also referred to as architectural or building glass, and the automotive trade (20%). A survey is given in figure 6.1.

¹Plate glass (Spiegelglas), sheet glass (Tafelglas), polished wire (Spiegeldrahtglas) and patterned glass (Ornamentglas). The German expressions are given because of the specialized terminology.

²Tönen, bzw. Online-Beschichtung.

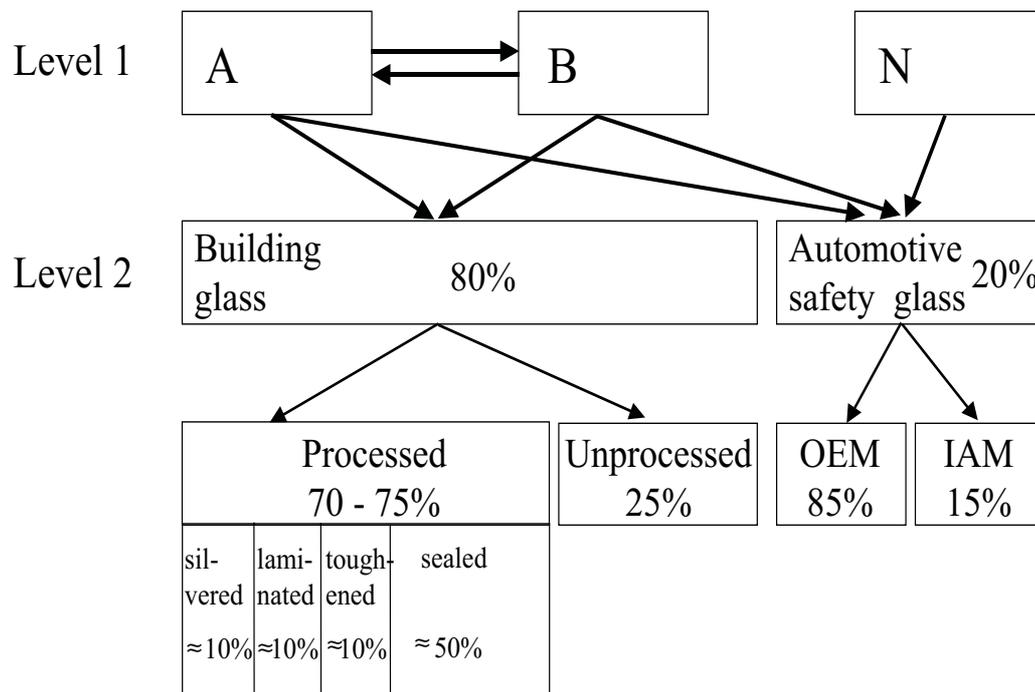


Figure 6.1: Flat glass market structure

General Trade Glass

More than 70% of the raw float glass in this sector is further processed. For processed glass there are following separate relevant product markets: silvered glass (10%), laminated glass (10%), toughened glass (10%) and sealed glass (50%)³. Unprocessed glass accounts for 25% of the market.

Automotive Trade Glass

Although there are two types of safety glass in the automotive market - laminated glass and toughened glass -, they are considered as belonging to the same relevant product market, i.e. the market for automotive safety glass. However, there are separate product markets for the original equipment sold to vehicle manufacturers, that is the original equipment manufacturer (OEM) and original equipment supply (OES), with a market share of about 85% and

³Silvered glass (verspiegeltes Glas), laminated glass (Verbundglas), toughened glass (thermisch gehärtetes Glas) and sealed glass (Mehrscheiben-Isolierglas, d.h. Doppel- oder Mehrfachglas).

replacement equipment, that is the independent after market (IAM) with about 15% market share. The geographical reference market for OEM/OES and IAM automotive safety glass is Community wide.

6.2 Competition Assessment

As to the European Commission, the proposed concentration did not create a dominant position for Pilkington/SIV either at level 1 or level 2, but might lead to a collective dominant position between the five major float glass producers in the Community (especially on level 1).

6.2.1 Assessment on Level 1

Market Shares

Five producers account for 96% of the Community supply of float glass. But the market shares are asymmetric and the level of aggregation is so large at the community level that it dampens or masks changes in the market share at national levels which are indicative of past competition.

According to the federation of European Glass Producers (GEPVP) the following companies were producers of float glass in the 15 EU countries with tanks operating at the end of 1998.

Country	Manufacturer	Production Units
Belgium	Glaverbal S.A.	4 tanks
	Glaceries de Saint Roch S.A.	2 tanks
Holland	Maasglas N.V.	1 tank
Finland	Lahti	1 tank
France	Saint Gobain Vitrage S.A.	2 tanks
	Eurofloat S.A. (St. Gobain)	1 tank
	Glaverbel France	2 tanks
Germany	Euroglas	1 tank
	Flachglas AG	4 tanks
	Vegla (Vereinigte Glaswerke GmbH)	4 tanks
	Guardian	1 tank
Luxembourg	Trösch	1 tank
	Luxguard 1	1 tank
Italy	Luxguard 2	1 tank
	Saint Gobain Vetro Italia	1 tank
	S.I.V. SpA	2 tanks
U.K.	Flovetro SpA	1 tank
	Glaverbel Italy	2 tanks
Spain	Pilkington UK Ltd.	3 tanks
	Cristaleria Espanola S.A.	2 tanks
	Vidreria de Llodio	1 tank
Sweden	Guardian Spain	1 tank
	PFAB	1 tank
Portugal	Covina	1 tank
Total EU		41 tanks

Product and Market Characteristics

The structural interdependence is high. The minimum efficient production volume of a new float plant is 150 000 tonnes a year with capital costs of about 100 million ECU and a new plant will be felt by other producers since it is not feasible to operate at low output levels.

The mature market has an increasing overcapacity (7-22%). The elasticity of demand is very low and a strong incentive exists to engage in cartel-like, i.e. parallel behaviour. The nominal price of the benchmark 4 mm thick clear float glass fell in the beginning of the 90s by 30% within 3 years and profitability of float glass producers has fallen.

As to the federation GEPVP, other producers impacting on the EU market with the following float tanks either existing or planned, are as follows.

Country	Existing	Under construction or definitively planned
Bielo-Russia, Russia, Ukraine	13	2 (end 1998)
Czech Republic	2	
Egypt	1	
Hungary	1	
Israel	1	
Poland	2	
Romania	1	
Turkey	3	

New capacity in the EU is expected to be as follows.

Country	Company	Capacity (T/Day) (Under construction or definitively planned up to 2001)	Approx. Startup Date
U.K.	Saint-Gobain	500	end 1999
Italy	Sangalli	500 (state aid under review)	end 2000 ?
Spain	Glaverbel/Pilkington	500	mid-2000
France	Interpane	550	end 2000

Market transparency

Price transparency cannot be obtained from producer price lists, if at all then rather from buyers. Producer links like technological product licence agreements, cross-supply links⁴ or joint venture links are insufficient or irrelevant in this particular case to create collective dominance.

Production costs and product heterogeneity

Fixed costs amount for approximately 65% of total costs. No float glass producer enjoys a substantial cost advantage relative to other producers. As 70% of primary float glass is subject to further processing, research and innovation is increasingly important as manufacturers extend the range of value added products. Product innovation leads to product differentiation. New market entry is usually unlikely.

Stability of possible anti-competitive parallel behaviour seems unlikely. There is an incentive to renege on tacit parallel behaviour (tacit price understanding) due to low variable costs and an individual price elasticity of

⁴Subcontracting (Querlieferbeziehungen)

demand faced by a single firm which appears to be higher than the elasticity of demand at the overall market level. Asymmetrical vertical integration undermines the feasibility of parallel behaviour at level 1, so does new capacity.

*Cross-supplies*⁵

There is a history of cross-supplies between producers. In the beginning of the 90s they typically varied between 3% and 7% of production volume (for both sales and purchases) due to genuine technical reasons or urgent small orders i.e. for tinted glass. For SIV they are large (over 60% of its automobile glass requirements from Pilkington). In tandem with the decline in demand in the beginning of the 90s there has been a substantial reduction in the volume of cross-supply sales.

6.2.2 Assessment at level 2 - general trade

The supply chain to the end user is very complicated. The six float glass producers have a combined market share of approximately 80% for silvered glass, 60% for laminated glass, 65% for toughened glass and 30% for sealed units. Pilkington/SIV would not acquire a dominant position. The creation of collective dominance at level 2 is unlikely as long as there are independent processors with significant market share and ease of entry and as long as there is competitive supply of raw float glass from level 1.

6.2.3 Assessment at level 2 - automotive trade

In the OEM/OES sector only the float glass producers (and Solvier) are suppliers, in the IEM sector there are many more independent suppliers (at least 10).

In the OEM/OES sector there is no collective dominance and no duopoly because demand side purchasing power and excess capacity in the beginning of the 90s (20-35% for laminated glass and 15-40% for toughened glass). In the IAM sector there is a large number of independent suppliers and it is not in the interest of float glass producers to weaken the position of IAM outlets.

⁵A different terminology for one-sided or two-sided subcontracting.

6.3 Conclusion

The European Commission basically drew a favourable picture of competition in the flat glass market when deciding on the Pilkington/SIV case. Concentration would likely increase in an industry which already had strong incentives to engage in collusive behaviour. But particularly in the beginning of the 90s, the float glass market suffered from increased excess capacity and a decline in demand, leading to price decreases of upto 30%. In the general trade there are many independent processors and distributors downstream. In the automotive trade vehicle manufacturers can exert considerable purchasing power. In its assessment, asymmetries in the market position of the remaining 5 float glass producers, insufficient market transparency and excess capacity would render creation and stability of possible collusive behaviour difficult.

The description of the market explains the assumptions made particularly for the horizontal subcontracting model. This concerns the technologically given plant sizes, high fixed costs and the need to lumpy investments when demand changes. Furthermore, the starting point of the Italian flat glass case, where the European Commission forbid subcontracting, is also one of horizontal subcontracting, where one company subcontracted almost all of its floatglass from a competitor (similarly, see SIV buying about 60% of its automotive glass from Pilkington). Two aspects are of particular interest: insufficient market transparency, with direct relevance to information sharing and signaling, and excess capacity. Both aspects were crucial in the subcontracting models analyzed. In the case of information sharing, this is straightforward. In the case of excess capacity, one has to remember, that the results of the subcontracting model with capacity decisions depended on the ratio of the demand level to plant capacity, i.e. capacity utilization. Varying degrees of demand would lead to changes in the pattern of subcontracting, just as the subcontracted quantities (cross-supplies) actually declined with excess capacity.

CPIV
COMITE PERMANENT DES INDUSTRIES DU VERRE
DE L'UNION EUROPEENNE

06/99

EU GLASS PRODUCTION

000 t	FLAT GLASS	CONTAINER	TABLEWARE *	FIBRES [●]	OTHERS *
EUR-10					
1980	4 090	12 173	1 025	223	680
1981	4 160	11 247	801	204	448
1982	4 176	11 478	822	204	488
1983	4 365	11 623	861	225	474
1984	4 638	11 972	893	249	611
1985	4 665	11 820	895	276	514
EUR-12					
1986	4 683	12 160	859	286	544
1987	4 804	12 631	870	296	706
1988	5 236	13 388	897	320	756
1989	5 254	13 601	954	350	811
1990	5 648	14 290	981	373	838
1991	5 357	15 372	1 032	327	864
1992	5 695	15 304	967	341	955
1993	5 797	14 932	911	341	928
1994	6 207	15 824	963	371	1 064
1995	6 168	16 374	979	466	1 421
EUR-15					
1995	6 458	16 898	998	488	1 531
1996	6 390	17 322	1 041	487	1 526
1997	6 893	17 316	1 046	475	1 557
1998	7 277	17 676	1 025	506	1 622

D : former BRD until 1991

EUR-10 : Benelux, Denmark, France, Germany, Greece, Italy, Ireland & United-Kingdom

EUR-12 : including Portugal and Spain

EUR-15 : including Austria, Finland & Sweden

* without Spain

● Reinforcement fibres

Flat glass sector : Total untransformed flat glass, with estimates based on saleable capacity for Member States without national glass federations (i.e. Spain, Portugal, Greece, Luxemburg, Denmark, and Finland and Sweden for EUR-15).

TOTAL (in million tonnes)

1980	18.20	1986	18.54	1992	23.26	1998	28.11
1981	16.86	1987	19.31	1993	22.91		
1982	17.17	1988	20.60	1994	24.43		
1983	17.55	1989	20.97	1995	(25.40)26.41		
1984	18.36	1990	22.13	1996	26.77		
1985	18.17	1991	22.95	1997	27.28		



Appendix

Appendix A

A.1 Proof of Proposition (3) (Unique separating equilibrium)

The proof of proposition (3) will make use of Lemma (18).

Lemma 18 (*Subcontracting effect*): *The subcontracting effect is positive if the beliefs do not change.*

Proof. $\frac{\partial E\pi_1}{\partial t}|_{c^e=const} \geq 0$. ■

The subcontracting price t influences firm 1's expected profit through a subcontracting and an expectation effect: $\frac{dE\pi_1(c_i, t, c^e(t))}{dt} = \frac{\partial E\pi_1}{\partial t} + \frac{\partial E\pi_1}{\partial c^e(t)} c^e'(t)$. The subcontracting effect is straightforward. Selling the product to the competitor at a higher price is always more profitable, as long as the competitor continues to subcontract (buy), i.e. $t \leq 1$, and as long as the expectations do not change ($c^e(t) = const$). Then derivation yields the subcontracting effect $\frac{\partial E\pi_1}{\partial t} = \frac{1}{9}(10 + 2c^e + 3c_i - 10t) \geq 0$ if $t \leq 1$. In the following proof it is therefore crucial to check in the belief function whether a deviation of t changes the beliefs employed in the deviation profit ($t \leq t^*$) and whether the other firm stops subcontracting ($t > 1$). If the beliefs do not change and subcontracting (or not subcontracting) continues, then firm 1's profit increases with t .

A.1.1 Separating equilibrium

The proof consists of two parts. First, take the beliefs as given. Then for every type, deviation from the equilibrium strategies is not profitable, i.e.

the self-selection conditions $\pi_1(c_i, t_i^*, c_i) \geq \pi_1(c_i, t, c^e(t))$ ($i = l, h$) have to hold for all t . Secondly, take the equilibrium strategies as given. Then the beliefs have to be self-fulfilling.

1. Take the beliefs $\mu_l(t) = \begin{cases} 1 & \text{if } t \leq t^* \\ 0 & \text{if } t > t^* \end{cases}$ as given. Now look for conditions under which none of the types will deviate.

(i) Low-cost type firm 1 ($c_i = c_l$) chooses t_l .

Note that a low-cost firm's subcontracting price t_l has to be less than 1 (implying $t^* \leq 1$). Otherwise firm 2 does not subcontract (buy) and a low-cost firm could not successfully "separate" itself from a high-cost firm. First consider deviations $t < t_l$.

If $t < t_l \leq t^* \leq 1$ then $\pi_1(c_l, t_l, c_l) \geq \pi_1(c_l, t, c_l)$ because due to Lemma (18) deviation to a lower $t < t_l$ leads to lower profits. The Lemma can be applied because the beliefs do not change with deviation.

Now consider deviations $t > t_l$.

If $t_l < t \leq t^* \leq 1$ then $\pi_1(c_l, t_l, c_l) \geq \pi_1(c_l, t, c_l)$ can only hold due to Lemma (18) if $t_l \geq t^*$. Furthermore, $t_l \leq t^*$ in order to signal low-costs. This leads to the result that

$$t_l = t^* (\leq 1) \quad (\text{A.1})$$

If $t_l = t^* < t \leq 1$ the beliefs $c^e(t)$ in the profit function change from c_l to c_h . Now even the potentially most profitable deviation at $t = 1$ has to be excluded. Then $\pi_1(c_l, t_l, c_l) \geq \pi_1(c_l, 1, c_h)$ if

$$t_l \geq 1 + \frac{c_l}{2} - \frac{1}{2\sqrt{5}}(\sqrt{c_h(6c_l - c_h)}) = t_{\min 1} \quad (\text{A.2})$$

Then from $0 \leq t_l \leq 1$ it follows that

$$c_l \leq c_h \leq 5c_l \quad (\text{A.3})$$

For this range of cost parameters if $1 \geq t_l \geq t_{l \min 1}$ then deviating is not profitable. Equation (A.3) defines two **boundaries of region I** in figure (2.1). (Remark: The profit difference $\pi_1(c_l, t_l, c_l) - \pi_1(c_l, 1, c_h)$ is a downward sloping parabola for which the first order conditions yield two values of t_l for zero profit differences. In the relevant subcontracting range $0 \leq t_l \leq 1$ marginal profit differences are positive so t_l has to be larger than the lower of the two values t_{\min} . The condition $0 \leq t_{\min} \leq t \leq 1$ yields two border solutions for $t_{\min} = 0$ and $t_{\min} = 1$. Solving for c_h yields the restrictions on

the cost parameters in equation (A.3) at which $1 \geq t_l \geq t_{\min 1}$ holds and at which deviation is not profitable.)

If $t_l = t^* \leq 1 < t$ then because $t > 1$ firm 2 would not subcontract. (Remember that the notation was defined as $t = \text{'' - ''}$ if $t > 1$ to indicate that no subcontracting occurs.) Then $\pi_1(c_l, t_l, c_l) \geq \pi_1(c_l, -, c_h)$ if

$$t_l \geq 1 + \frac{c_l}{2} - \frac{1}{2\sqrt{5}}(\sqrt{c_h(12 - c_h - 6c_l)}) = t_{\min 2} \quad (\text{A.4})$$

Then from $0 \leq t_l \leq 1$ it follows that

$$c_h \geq 6 - 3c_l - 2\sqrt{9 - 9c_l + c_l^2} \quad (\text{A.5})$$

In fact, this condition need only to be checked if $c_l > 1$. Otherwise, if $c_l \leq 1$, deviating to $t > 1$ would end the profitable subcontracting and change beliefs from c_l to the less profitable c_h . Deviating would therefore never be more profitable. Equation (A.5) defines the **border between region II and region III** in figure (2.1).

(ii) High-cost type firm 1 ($c_i = c_h$) chooses t_h . First consider deviations $t_h < t$.

If $t^* \leq 1 < t_h < t$ then $\pi_1(c_h, -, c_h) \geq \pi_1(c_h, -, c_h)$. In both cases no subcontracting occurs.

If $t^* < t_h < t \leq 1$ then $\pi_1(c_h, t_h, c_h) \geq \pi_1(c_h, t, c_h)$ can never hold due to Lemma (18). The case $t_h < t \leq 1$ can be excluded if $t_h \geq 1$. The case $t_h > 1$ was checked above and deviation was not profitable. So now check for $t_h = 1$.

If $t^* < t_h = 1 < t$ then $\pi_1(c_h, 1, c_h) \geq \pi_1(c_h, -, c_h)$ if $c_h \leq 1$. This implies

$$\begin{aligned} \text{If } c_h \leq 1 \text{ then } t_h &= 1 \\ \text{If } c_h > 1 \text{ then } t_h &> 1. \end{aligned} \quad (\text{A.6})$$

The interpretation is as follows. If the production costs are low, $c_h \leq 1$, charging the highest price with subcontracting, $t_h = 1$, leads to the highest possible profit and deviating to a higher price would end profitable subcontracting. If production costs are high, $c_h > 1$, subcontracting at $t_h = 1$ generates losses and deviating to a higher $t > 1$ would end loss-making subcontracting and be more profitable. Therefore, a necessary condition for a separating equilibrium with $t_h = 1$ is that $c_h \leq 1$.

Now consider deviations $t < t_h$.

If $t^* \leq 1 < t < t_h$ then $\pi_1(c_h, -, c_h) \geq \pi_1(c_h, -, c_h)$. In both cases no subcontracting occurs.

If $t^* < t \leq 1 < t_h$ then $\pi_1(c_h, -, c_h) \geq \pi_1(c_h, t, c_h)$ if

$$t \leq 1 + \frac{c_h}{2} - \frac{1}{2\sqrt{5}}\sqrt{(12 - 7c_h)c_h} = t_{\max 1} \quad (\text{A.7})$$

In particular, this condition has to hold for the highest possible deviation t at $t = t_{\max 1} = 1$. Then from $t = t_{\max 1} \leq 1$ it follows that $c_h \leq 1$. But if $c_h < 1$ then $t_{\max 1} < t \leq 1$ would always be a profitable deviation and therefore $t_h > 1$ cannot be part of a separating equilibrium if $c_h < 1$. It follows that

$$\text{If } c_h < 1 \text{ then } t_h \leq 1. \quad (\text{A.8})$$

If $t \leq t^* \leq 1 < t_h$ then $\pi_1(c_h, -, c_h) \geq \pi_1(c_h, t, c_l)$ if

$$t \leq \frac{1}{10}(10 + 3c_h + 2c_l - \sqrt{60c_h - 26c_h^2 - 18c_h c_l + 9c_l^2}) = t_{\max 2} \quad (\text{A.9})$$

This always holds if

$$t^* \leq t_{\max 2}$$

because then $t \leq t^* \leq t_{\max 2}$. The condition $t^* = t_{\max 2} \leq 1$ yields

$$c_h \leq \frac{1}{7}(6 - 3c_l + 2\sqrt{9 - 9c_l + 4c_l^2}) \quad (\text{A.10})$$

This is the region of cost parameters at which a low-cost firm has to set its subcontracting price low enough ($t^* \leq t_{\max 2}$) so that it would not be profitable for a high-cost firm to mimick the low-cost firm. Note the crucial fact, stated in corollary , that in this cost region the price t^* is always less (or equal) than 1. In other cost regions the equation always holds. Equation (A.10) describes the **border between region I and region II** in figure (2.1).

If $t^* < t < t_h = 1$ then $\pi_1(c_h, 1, c_h) \geq \pi_1(c_h, t, c_h)$ due to Lemma (18).

If $t \leq t^* < t_h = 1$ then $\pi_1(c_h, 1, c_h) \geq \pi_1(c_h, t, c_l)$ if

$$t \leq \frac{1}{10}(10 + 3c_h + 2c_l - \sqrt{34c_h^2 - 18c_h c_l + 9c_l^2}) = t_{\max 3} \quad (\text{A.11})$$

This will always hold, similar to the considerations of equation (A.9), if

$$t^* \leq t_{\max 3}$$

Then from $0 \leq t^* \leq 1$ it follows that

$$c_h \geq c_l \tag{A.12}$$

Necessary and sufficient conditions

Equations (A.1)-(A.12) give the sufficient conditions that neither a low-cost nor a high-cost type profits from deviation.

For the low-cost type, from equations (A.1) to (A.5) it follows that

$$\begin{aligned} t_l &= t^* \\ t_l &\geq t_{\min 1} \quad \text{if } c_l \leq c_h \leq 5c_l && \text{(in region I and II)} \\ t_l &\geq t_{\min 2} \quad \text{if } c_h \geq 6 - 3c_l - 2\sqrt{9 - 9c_l + c_l^2} && \text{(in region I and II)} \end{aligned}$$

Then the first set of conditions yields

$$t_l = t^* \in [\max\{t_{\min 1}, t_{\min 2}\}, 1]$$

Making use of the fact that $t_{\min 1} \geq t_{\min 2}$ if $c_l \leq 1$ leads to the more precise statement that

$$t_l = t^* \in \begin{cases} [t_{\min 1}, 1] & \text{if } c_l \leq 1, c_l \leq c_h \leq 5c_l && \text{(region I and IIa)} \\ [t_{\min 2}, 1] & \text{if } c_l > 1, c_h \geq 6 - 3c_l - 2\sqrt{9 - 9c_l + c_l^2} && \text{(region IIb)} \end{cases}$$

See figure (2.1) for a picture of the regions. The regions are defined in equation (A.15).

For the high-cost type, from equations (A.6) to (A.12) it follows that

$$\begin{aligned} t_h &= 1 && \text{if } c_h \leq 1 && \text{(region Ia)} \\ t_h &> 1 && \text{if } c_h > 1 && \text{(region Ib and II)} \\ t_l &\leq t_{\max 2} && \text{if } c_h > 1, c_h \leq \frac{1}{7}(6 - 3c_l + 2\sqrt{9 - 9c_l + 4c_l^2}) && \text{(region Ib and II)} \\ t_l &\leq t_{\max 3} && \text{if } c_h \leq 1, c_l \leq c_h && \text{(region Ia)} \end{aligned}$$

Then the sufficient conditions for a separating equilibrium can be summarized

$$t_l = t^* \in \begin{cases} [t_{\min 1}, \min\{t_{\max 3}, 1\}] = [t_{\min 1}, t_{\max 3}] & \text{if region Ia} \\ [t_{\min 1}, \min\{t_{\max 2}, 1\}] = [t_{\min 1}, t_{\max 2}] & \text{if region Ib} \\ [t_{\min 1}, \min\{t_{\max 2}, 1\}] = [t_{\min 1}, 1] & \text{if region IIa} \\ [t_{\min 2}, \min\{t_{\max 2}, 1\}] = [t_{\min 2}, 1] & \text{if region IIb} \end{cases} \quad (\text{A.13})$$

$$t_h = \begin{cases} 1 & \text{if region Ia} \\ - & \text{if otherwise} \end{cases} \quad (\text{A.14})$$

Note that the interval boundaries depend on the cost regions because the cost regions determine the strategies from which a deviation shall not be profitable. Take e.g. region Ia. In region Ia it holds that $c_h < 1$ and therefore $t_h = 1$. It is now important to realize that only deviations from $t_h = 1$ have to be checked as being unprofitable. A high-cost firm must not have an incentive to deviate from $t_h = 1$ and e.g. set a lower price and mimick a low-cost firm. This is checked in equation (A.11) and leads to the condition $t_l \leq t_{\max 3}$. It is not necessary that $t_l \leq t_{\max 2}$ holds as well because this is the condition determining when a deviation from $t_h = -$ (i.e. $t_h > 1$) is unprofitable. In fact, $t_h = -$ only holds if $c_h > 1$, that is in all regions except region Ia.

Existence

Separating equilibria exist if the price t_l of a low-cost firm is an element of a non-empty interval. This has to be checked for every interval in equation (A.13). In region Ia a separating equilibrium cannot exist because $t_{\min 1} > t_{\max 3}$ if $c_h > c_l$ (which is the case in region Ia) and therefore the interval is empty. In region Ib numerical calculations show that except for a small corner to the lower left in region Ib it always holds that $t_{\min 1} < t_{\max 2}$. In region IIa and IIb the lower limits $t_{\min 1}$ and $t_{\min 2}$ are always less than 1 as this is exactly the condition determining the boundaries of these regions. Then infinitely many separating equilibria exist with prices

$$(t_l, t_h) \in \begin{cases} ([t_{\min 1}, t_{\max 2}], -) & \text{if region Ib} \\ ([t_{\min 1}, 1], -) & \text{if region IIa} \\ ([t_{\min 2}, 1], -) & \text{if region IIb} \\ \text{no offer} & \text{if otherwise} \end{cases}$$

Uniqueness

The "intuitive criterion" selects the best separating equilibrium with the highest profits for the uninformed firm. According to Lemma (18) the low-cost firm profits increase with t_l as long as the beliefs do not change. Then the unique separating equilibrium is

$$(t_l^*, t_h^*) = \begin{cases} (t_{\max 2}, -) & \text{if region Ib} \\ (1, -) & \text{if region IIa} \\ (1, -) & \text{if region IIb} \\ \text{no offer} & \text{if otherwise} \end{cases}$$

with $t_{\max 2}$ as defined in equation (A.9). The regions are shown in figure (2.1) and are defined as

Region Ia	$c_h \leq 1, c_l \leq c_h \leq 5c_l$
Region Ib	$c_h > 1, c_l \leq c_h \leq 5c_l, c_h \leq \frac{1}{7}(6 - 3c_l + 2\sqrt{9 - 9c_l + 4c_l^2})$
Region IIa	$c_h > \frac{1}{7}(6 - 3c_l + 2\sqrt{9 - 9c_l + 4c_l^2}), c_h \geq 6 - 3c_l - 2\sqrt{9 - 9c_l + c_l^2}$
Region IIb	$c_l \leq c_h \leq 5c_l, c_h < 6 - 3c_l - 2\sqrt{9 - 9c_l + c_l^2}$

(A.15)

The additional assumption $c_h < 1.5$ guarantees that a high-cost firm which does not subcontract makes positive profits and it defines the upper bound in figure (2.1).

Firms' equilibrium sales are given according to proposition (1).

2. Take the equilibrium strategies as given, in particular that the equilibrium price t_l^* is equal to the price t^* given in the belief function. Then the beliefs are self-fulfilling. The low-cost type firm chooses $t_l = t^*$, leading to beliefs that with certainty this firm is a low-cost firm, and the high-cost type firm chooses a higher price, leading to the belief that this firm is a high-cost firm. ■

A.2 Proof of Proposition (4) (Pooling Equilibria)

It holds that $c^e(t) = \mu_l(t)c_l + (1 - \mu_l(t))c_h$. For given beliefs $\mu_l(t) = \begin{cases} p_l & \text{if } t = t^* \\ 0 & \text{if } t \neq t^* \end{cases}$ it follows that if $t \neq t^* = 1$ then $c^e(t^*) = c^e(1) = p_l c_l + (1 - p_l)c_h$ and $c^e(t) = c_h$. Furthermore, note that subcontracting only

occurs at a pooling price $t^* \leq 1$, otherwise firm 2 would prefer to produce on its own.

1. Take the beliefs as given. Now look for conditions under which none of the types will deviate.

(i) Low-cost type firm 1 ($c_i = c_l$) chooses t^* .

If $t^* < t \leq 1$ then $\pi_1(c_l, t^*, c^e(t^*)) \geq \pi_1(c_l, t, c_h)$ can never hold for all possible probabilities p_l . Due to Lemma (18) this condition e.g. never holds for $p_l = 0$. It follows that

$$t^* = 1$$

If $t < t^* = 1$ then $\pi_1(c_l, 1, c^e(1)) \geq \pi_1(c_l, t, c_h)$ if

$$t \leq t_{\min 1} = \frac{1}{10} \frac{(10 + 2c_h + 3c_l - \sqrt{c_h^2(4 + 10p_l - 5p_l^2) + c_l^2(9 + 30p_l - 5p_l^2) + 2c_h c_l(6 - 20p_l + 5p_l^2)})}{10}$$

This always holds if $1 \leq t_{\min 1}$ which is equivalent to

$$c_l \leq c_h \leq \frac{p_l - 6}{p_l - 2} c_l \quad (\text{A.16})$$

Equation (A.16) defines two **boundaries of region I**.

If $t > t^* = 1$ then $\pi_1(c_l, 1, c^e(1)) \geq \pi_1(c_l, -, c_h)$ if

$$c_h \geq \frac{1}{p_l(p_l - 2)} (c_l(6 - 4p_l + p_l^2) - 2(3 + \sqrt{9 + c_l^2(3 - 2p_l)^2 - 3c_l(6 - 4p_l + p_l^2)})) \quad (\text{A.17})$$

Equation (A.17) defines the **border between region II and region III**.

(ii) High-cost type firm 1 ($c_i = c_h$) chooses t^* .

If $t < t^* = 1$ then $\pi_1(c_h, 1, c^e(1)) \geq \pi_1(c_h, t, c_h)$ if

$$t \leq 1 + \frac{c_h}{2} - \frac{1}{2\sqrt{5}} \sqrt{-c_l^2 p_l^2 + 2c_h c_l p_l(2 + p_l) - c_h^2(-5 + 4p_l + p_l^2)} = t_{\min 2}$$

This always holds if $1 \leq t_{\min 2}$ which is equivalent to

$$c_l \leq c_h \quad (\text{A.18})$$

(It is also equivalent to the irrelevant case $c_h \leq \frac{p_l}{4+p_l} c_l$). Equation (A.18) defines the lower **boundary of region I**.

If $t > t^* = 1$ then $\pi_1(c_h, 1, c^e(1)) \geq \pi_1(c_h, -, c_h)$ if

$$c_h \leq \frac{1}{p_l^2 + 4p_l - 12} (c_l p_l(2 + p_l) - 2(3 + \sqrt{9 + 4c_l^2 p_l^2 - 3c_l p_l(2 + p_l)})) \quad (\text{A.19})$$

Equation (A.19) defines the **border between region I and region II**.

In a pooling equilibrium all four equations (A.16)-(A.19) have to hold. This is the case in region I where the upper bounds shift inward with decreasing probability p_l :

$$t^* = \begin{cases} 1 & \text{if } \text{region } I_{\text{pooling}} \\ \text{no offer} & \text{if } \text{otherwise} \end{cases}$$

Region I_{pooling} : $c_l \leq c_h \leq \frac{p_l - 6}{p_l - 2} c_l$, $c_h \leq \frac{1}{p_l^2 + 4p_l - 12} (c_l p_l (2 + p_l) - 2(3 + \sqrt{9 + 4c_l^2 p_l^2 - 3c_l p_l (2 + p_l)}))$

(A.20)

2. For given strategies the beliefs are self-fulfilling. In a pooling equilibrium the low-cost type firm and the high-cost type firm both choose t^* , thereby revealing no information and leading to beliefs that firm 1 is a low-cost type with the a priori probability p_l . ■

Appendix B

For the basic framework for solving the profit functions see the chapter on nonlinear programming with nonnegativity constraints in Berck/Sydsaeter (1993). Applying this to the case of a firm producing two products $\mathbf{x} = \{x_1, x_2\}$, $\mathbf{x} \geq 0$ in different plants each of capacity K , so that $g_i(\mathbf{x}) = x_i$, leads to

$$\max_{\mathbf{x}} f(\mathbf{x}) \quad \text{with} \quad \begin{cases} g_1(x_1, x_2) \leq K \\ g_2(x_1, x_2) \leq K \end{cases} \quad (\text{B.1})$$

$$L(\mathbf{x}, \boldsymbol{\lambda}) = f(\mathbf{x}) - \sum_{j=1}^2 \lambda_j (g_j(\mathbf{x}) - K)$$

For the vectors $\boldsymbol{\lambda}^0 = (\lambda_1^0, \lambda_2^0)$ and $\mathbf{x}^0 = (x_1^0, x_2^0)$ the sufficient Kuhn-Tucker conditions are:

- $\frac{\partial L(\mathbf{x}^0, \boldsymbol{\lambda}^0)}{\partial x_i} = 0$, $i = 1, 2$
- $\frac{\partial L(\mathbf{x}^0, \boldsymbol{\lambda}^0)}{\partial \lambda_j} \geq 0$ and $\lambda_j^0 \frac{\partial L(\mathbf{x}^0, \boldsymbol{\lambda}^0)}{\partial \lambda_j} = 0$, $j = 1, 2$; $\lambda_j^0 \geq 0$.
- the Lagrangean function $L(\mathbf{x}, \boldsymbol{\lambda})$ is a concave function of \mathbf{x} .

Then \mathbf{x}^0 solves the problem (B.1).

Most of the calculations and graphics were done with Mathematica.

B.1 Duopoly without subcontracting

B.1.1 Profit functions

The market size of product x is a_1 , the market size of product y is a_2 .

Case (f,f)

Firm 1 produces product x in one plant and firm 2 produces product y in one plant. Due to symmetry $x_1 = y_2$ and $\pi_1^{x,y} = \pi_2^{x,y}$. Solving explicitly, at least for this case, leads to the profit functions

$$\pi_1^{x,y} = (a_1 - x_1)x_1 - \lambda(x_1 - K)$$

The Kuhn-Tucker conditions are

$$\begin{aligned} a_1 - 2x_1 - \lambda &= 0 \\ -(x_1 - K) &\geq 0 \quad \text{and} \quad -(x_1 - K)\lambda = 0 \end{aligned}$$

If the capacity constraint is not binding, that is if $\lambda = 0$, then the Kuhn-Tucker conditions lead to $x_1 = \frac{a_1}{2}$ and $K \geq x_1 = \frac{a_1}{2}$. In summary:

If $\frac{a_1}{2} \leq K$ then firm 1 is not capacity constrained. Optimal quantities and profits are $x_1 = \frac{a_1}{2}$ and $\pi_1^{x,y} = (\frac{a_1}{2})^2$.

If $\frac{a_1}{2} > K$ then firm 1 is capacity constrained, $x_1 = K$ and $\pi_1^{x,y} = (a_1 - K)K$.

Then for the example $K = 1, a_1 = a_2 = a$ it holds that

$$f = \pi_1^{x,y} = \pi_2^{x,y} = \begin{cases} (\frac{a}{2})^2 & \text{if } 0 < a \leq 2 \\ a - 1 & \text{if } 2 < a \end{cases}$$

Case (g,h)

Firm 1 produces products x and y in one plant and firm 2 produces product y in one plant.

If $\frac{a_1}{2} + \frac{a_2}{3} \leq K$ neither of the two firms is capacity constrained. Then $(x_1, y_1, y_2) = (\frac{a_1}{2}, \frac{a_2}{3}, \frac{a_2}{3})$, $\pi_1^{xy,y} = (\frac{a_1}{2})^2 + (\frac{a_2}{3})^2 - F_w$ and $\pi_2^{xy,y} = (\frac{a_2}{3})^2$.

If $\frac{1}{9}(a_1 + 3a_2) \leq K < \frac{a_1}{2} + \frac{a_2}{3}$ only firm 1 is capacity constrained. Then $(x_1, y_1, y_2) = (\frac{1}{7}(2a_1 - a_2 + 3K), \frac{1}{7}(a_2 - 2a_1 + 4K), \frac{1}{7}(a_1 + 3a_2 - 2K))$

$$\pi_1^{xy,y} = \frac{1}{49}(8a_1^2 - 8a_1a_2 + 2a_2^2 + 17a_1K + 16a_2K - 17K^2) - F_w$$

$$\pi_2^{xy,y} = \frac{1}{49}(a_1 + 3a_2 - 2K)^2$$

If $K < \frac{1}{9}(a_1 + 3a_2)$ both firms are capacity constrained. Then

$$(x_1, y_1, y_2) = (\frac{1}{4}(a_1 - a_2 + 3K), \frac{1}{4}(a_2 - a_1 + K), K)$$

$$\pi_1^{xy,y} = \frac{1}{8}((a_1 - a_2)^2 + 6a_1K + 2a_2K - 7K^2) - F_w$$

$$\pi_2^{xy,y} = \frac{1}{4}(a_1 + 3a_2 - 5K)K$$

Then for the example $K = 1, a_1 = a_2 = a$ it holds that

$$g = \pi_1^{xy,y} = \begin{cases} \frac{13}{36}a^2 - F_w & \text{if } 0 < a \leq \frac{6}{5} \\ \frac{1}{49}(33a + 2a^2 - 17) - F_w & \text{if } \frac{6}{5} < a \leq \frac{6}{4} \\ a - \frac{7}{8} - F_w & \text{if } \frac{6}{4} < a \end{cases}$$

$$h = \pi_2^{xy,y} = \begin{cases} \frac{a^2}{9} & \text{if } 0 < a \leq \frac{6}{5} \\ \frac{1}{49}(4a - 2)^2 & \text{if } \frac{6}{5} < a \leq \frac{6}{4} \\ a - \frac{5}{4} & \text{if } \frac{6}{4} < a \end{cases}$$

Case (k,k)

Firm 1 and Firm 2 have one plant each and produce both products in their plant. Due to symmetry $x_1 = x_2, y_1 = y_2$ and $\pi_1^{xy,xy} = \pi_2^{xy,xy}$.

If $\frac{a_1+a_2}{3} \leq K$ neither of the two firms is capacity constrained. Then

$$(x_1, y_1) = \left(\frac{a_1}{3}, \frac{a_2}{3}\right) \text{ and } \pi_1^{xy,xy} = \left(\frac{a_1}{3}\right)^2 + \left(\frac{a_2}{3}\right)^2 - F_w.$$

If $K < \frac{a_1+a_2}{2}$ both firms are capacity constrained. Then

$$(x_1, y_1) = \left(\frac{1}{6}(a_1 - a_2 + 3K), \frac{1}{6}(a_2 - a_1 + 3K)\right)$$

$$\pi_1^{xy,xy} = \frac{1}{18}(a_1 - a_2)^2 + \frac{1}{2}(a_1 + a_2)K - K^2 - F_w$$

Then for the example $K = 1, a_1 = a_2 = a$ it holds that

$$k = \pi_1^{xy,xy} = \pi_2^{xy,xy} = \begin{cases} \frac{2}{9}a^2 - F_w & \text{if } 0 < a \leq \frac{3}{2} \\ a - 1 - F_w & \text{if } \frac{3}{2} < a \end{cases}$$

Case (m,l)

Firm 1 produces product x in one plant and product y in a second plant and firm 2 produces products x and y in one plant.

If $\frac{a_1+a_2}{3} \leq K$ then neither of the two firms is capacity constrained. Then

$$(x_1, y_1, x_2, y_2) = \left(\frac{a_1}{3}, \frac{a_2}{3}, \frac{a_1}{3}, \frac{a_2}{3}\right)$$

$$\pi_1^{xy;x,y} = \left(\frac{a_1}{3}\right)^2 + \left(\frac{a_2}{3}\right)^2 - F_n$$

$$\pi_2^{xy;x,y} = \left(\frac{a_1}{3}\right)^2 + \left(\frac{a_2}{3}\right)^2 - F_w.$$

If $\frac{5a_1+a_2}{15} < K, \frac{a_1+5a_2}{15} < K, K < \frac{a_1+a_2}{3}$ then only firm 2 is capacity constrained.

$$(x_1, y_1, x_2, y_2) = \left(\frac{5a_1+a_2-3K}{12}, \frac{a_1+5a_2-3K}{12}, \frac{a_1-a_2+3K}{6}, \frac{a_2-a_1+3K}{6}\right)$$

$$\pi_1^{xy;x,y} = \frac{1}{144}(5a_1 + a_2 - 3K)^2 + \frac{1}{144}(a_1 + 5a_2 - 3K)^2 - F_n$$

$$\pi_2^{xy;x,y} = \frac{1}{18}(a_1 - a_2)^2 + \frac{1}{4}K(a_1 + a_2 - K) - F_w$$

If $\frac{a_1+a_2}{4} > K, \frac{3a_1+a_2}{10} > K, \frac{a_1+3a_2}{10} > K$ then both firms are capacity constrained in each plant. Then

$$(x_1, y_1, x_2, y_2) = (K, K, \frac{a_1 - a_2 + 2K}{4}, \frac{a_2 - a_1 + 2K}{4})$$

$$\pi_1^{xy;x,y} = (a_1 + a_2 - 3K)K - F_n$$

$$\pi_2^{xy;x,y} = \frac{1}{8}((a_1 - a_2)^2 + 4(a_1 + a_2 - 12K)K) - F_w$$

Then for the example $K = 1, a_1 = a_2 = a$ it holds that

$$m = \pi_1^{xy;x,y} = \begin{cases} \frac{2a^2}{9} - F_n & \text{if } 0 < a \leq \frac{3}{2} \\ \frac{(2a-1)^2}{8} - F_n & \text{if } \frac{3}{2} < a \leq \frac{5}{2} \\ 2a - 3 - F_n & \text{if } \frac{5}{2} < a \end{cases}$$

$$l = \pi_2^{xy;x,y} = \begin{cases} \frac{2a^2}{9} - F_w & \text{if } 0 < a \leq \frac{3}{2} \\ \frac{2a-1}{4} - F_w & \text{if } \frac{3}{2} < a \leq \frac{5}{2} \\ a - \frac{3}{2} - F_w & \text{if } \frac{5}{2} < a \end{cases}$$

Case (n,o)

Firm 1 produces product x in one plant and product y in one plant and firm 2 produces product y in one plant.

If $K \geq \frac{a_1}{2}, K \geq \frac{a_2}{3}$ then neither firm is capacity constrained. Then $(x_1, y_1, y_2) = (\frac{a_1}{2}, \frac{a_2}{3}, \frac{a_2}{3}), \pi_1^{x,y;y} = \frac{a_1^2}{4} + \frac{a_2^2}{9} - F_n$ and $\pi_2^{x,y;y} = \frac{a_2^2}{9}$.

If $K < \frac{a_1}{2}, K \geq \frac{a_2}{3}$ then firm 1 is capacity constrained only with product x. Then $(x_1, y_1, y_2) = (K, \frac{a_2}{3}, \frac{a_2}{3}), \pi_1^{x,y;y} = \frac{a_2^2}{9} + a_1K - K^2 - F_n$ and $\pi_2^{x,y;y} = \frac{a_2^2}{9}$.

"Degenerate" cases will be omitted. The case that firm 1 is capacity constrained in both plants and firm 2 is not capacity constrained can not arise. This would necessitate $\frac{a}{3} > K \geq \frac{a}{3}$, a contradiction.

If $\frac{a_1}{2} > K, \frac{a_2}{3} > K$ then both firms are capacity constrained in every plant. Then $(x_1, y_1, y_2) = (K, K, K), \pi_1^{x,y;y} = a_1K + a_2K - 3K^2 - F_n$ and $\pi_2^{x,y;y} = a_2K - 2K^2$.

Then for the example $K = 1, a_1 = a_2 = a$ it holds that

$$n = \pi_1^{x,y;y} = \begin{cases} \frac{13a^2}{36} - F_n & \text{if } 0 < a \leq 2 \\ \frac{a^2}{9} + a - 1 - F_n & \text{if } 2 < a \leq 3 \\ 2a - 3 - F_n & \text{if } 3 < a \end{cases}$$

$$o = \pi_2^{x,y;y} = \begin{cases} \frac{a^2}{9} & \text{if } 0 < a \leq 2 \\ \frac{a^2}{9} & \text{if } 2 < a \leq 3 \\ a - 2 & \text{if } 3 < a \end{cases}$$

Case (p,p)

Each firm has two plants and produces product x and y in one plant each. Due to symmetry $x_1 = x_2, y_1 = y_2$ and $\pi_1^{x,y;x,y} = \pi_2^{x,y;x,y}$.

If $K \geq \frac{a_1}{3}, K \geq \frac{a_2}{3}$ then neither firm is capacity constrained and $(x_1, y_1) = (\frac{a_1}{3}, \frac{a_2}{3})$ and $\pi_1^{x,y;x,y} = \frac{1}{9}(a_1^2 + a_2^2) - F_n$.

If $\frac{a_1}{3} > K, \frac{a_2}{3} > K$ then both firms are capacity constrained in each plant. Then $(x_1, y_1) = (K, K)$ and $\pi_1^{x,y;x,y} = a_1K + a_2K - 4K^2 - F_n$

Then for the example $K = 1, a_1 = a_2 = a$ it holds that

$$p = \pi_1^{x,y;x,y} = \pi_2^{x,y;x,y} \begin{cases} \frac{2a^2}{9} - F_n & \text{if } 0 < a \leq 3 \\ 2a - 4 - F_n & \text{if } 3 < a \end{cases}$$

B.1.2 Critical levels of demand

The critical level of demand a_i in table 4.1.2 are calculated for the example with fixed costs $F_n = 0.25$ and $F_w = 0.1$. The intersection of two profit functions can be seen graphically and determines those parts of the profit functions which are relevant for calculating the critical demand levels.

$$\begin{array}{llll} g = f & \text{if } a_1 = 3\sqrt{F_w} = 0.94868 & & \text{with } 0 < a \leq \frac{6}{5} \\ m = k & \text{if } a_2 = \frac{3}{2} - \sqrt{2\sqrt{F_n - F_w}} = 2.04772 & & \text{with } \frac{3}{2} < a \leq \frac{5}{2} \\ p = l & \text{if } a_3 = \frac{3}{8}(3 + \sqrt{1 + 32(F_n - F_w)}) = 2.02812 & & \text{with } \frac{3}{2} < a \leq \frac{5}{2} \\ k = h & \text{if } a_4 = a_1 & & \text{with } 0 < a \leq \frac{6}{5} \end{array}$$

Firms increase capacity at the same demand levels if $a_2 > a_3$, which when solving for fixed costs is equivalent to $F_w < F_n < F_w + \frac{9}{50}$. Firms increase capacity at different demand levels if $F_n \geq F_w + \frac{9}{50}$.

B.1.3 Assumptions about fixed costs

Two two assumptions about fixed costs help circumvent some technical difficulties without changing any basic results.

The first assumption is that the fixed costs of building the first plant are sunk. The starting point is that of each firm operating one plant. The focus is not on entry decisions of firms into markets but of adjustment and expansion decisions of firms already operating in a market and considering the "entry" of new plants. From a technical point this eliminates the problem of having two asymmetric equilibria on a demand interval. If costs are not sunk, the profit functions f, k and p in figure 4.1 would shift downward by the amount

of fixed costs. At the critical demand level a_1 it would be a dominant strategy of firms to produce both products and equilibrium profits would change from f to k even if k were negative. This does not seem plausible. Instead of making losses firms can always stop producing products, the strategy space should be enlarged and include the possibility of producing nothing. Then, as long as profit k is negative, there would be two asymmetric equilibria, where one firm, e.g. firm 1, produces both products and the other firm produces no products. In this demand interval, in equilibrium firm 1 would earn monopoly profits for two products and firm 2's profits would be zero. When looking at the adjustment process for a slowly growing demand (or more correctly the comparative statics of different demand levels), this would lead to the implausible result, that firm 2 would first produce one product, then none, then two products. If the fixed costs of the first plant are sunk, profits $k(a_1) > 0$ and this problem does not arise. Firms gradually extend their product line.

The second assumption, $F_w < F_n < F_w + \frac{9}{50}$, guarantees that $a_2 > a_3$ and that there are no technical difficulties in the adjustment process similar to the ones described above. If instead $F_n \geq F_w + \frac{9}{50}$, that is $a_2 \leq a_3$, there would again be two asymmetric equilibria. Only one firm, e.g. firm 1, would at demand a_2 increase its capacity by one plant. Firm 1 would increase its output substantially because both firms were capacity constrained before. The higher the fixed costs of building a new plant, the less inclined will firm 2 be to increase its capacity as well. For the demand interval (a_2, a_3) there will be an asymmetric equilibrium. This is the case where $F_w = 0.05$ instead of $F_w = 0.1$. Then $a_2 = 2.13246 < a_3 = 2.14511$ and for the small range of demand $[a_1, a_2)$ firm 1 would be the only company increasing its capacity.

B.2 Duopoly with subcontracting

The steps for determining the optimal quantities, prices and profits were outlined in section 4.1.3. Here, the case (g_s, h_s) will be described in detail, for the similar cases (n_s, o_s) and (m_s, l_s) only the results will be given.

Case (g_s, h_s)

The profit of firm 1 is g_s , the profit of firm 2 is h_s . Firm 1 produces products x and y in one plant and firm 2 produces product y in one plant. In the third stage of the game firms determine the optimal quantities and the Lagrangean parameters by solving equations 4.1. They are different for

each of the three capacity cases where either no firm, firm 1 or both firms are capacity constrained.

No firm is capacity constrained: $(x_1, y_1, s, y_2) = (\frac{a+t}{3}, \frac{a}{3}, \frac{a-2t}{3}, \frac{a}{3})$

Only firm 1 is capacity constrained:

$$(x_1, y_1, s, y_2, l_1) = (\frac{6-3a+5t}{9}, \frac{6-3a+2t}{9}, \frac{6a-3-7t}{9}, \frac{6a-3-t}{9}, a - 1 - \frac{t}{3})$$

Both firms are capacity constrained:

$$(x_1, y_1, s, y_2, l_1, l_2) = (\frac{3(2-a+t)}{5}, \frac{2-a+t}{5}, \frac{4a-3-4t}{5}, 1, \frac{7a-9-2t}{5}, \frac{6a-12-t}{5})$$

In the second stage of the game firm 1 chooses the subcontracting price by solving equations 4.2 for each of the three capacity cases. Basically, firm 1 solves

$$\max_t g_s(t) \quad s.t. \quad h_s(t) \geq \begin{cases} f_{no\ cc} & \text{if } 0 \leq a < a_1 \\ k_{no\ cc} & \text{if } a_1 \leq a < 1.5 \\ k_{firm\ 1\ cc} & \text{if } 1.5 \leq a \end{cases}$$

$$\text{No firm is capacity constrained: } t = \begin{cases} \frac{2+\sqrt{5}a}{4} & \text{if } 0 \leq a < a_1 \\ \frac{a-\sqrt{a^2-9F_w}}{2} & \text{if } a_1 \leq a < 1.5 \end{cases}$$

Only firm 1 is capacity constrained:

$$t = \begin{cases} - (\text{because } l_1 < 0) & \text{if } 0 \leq a < a_1 \\ \frac{3}{50}(-8 + 16a - \sqrt{2}\sqrt{-18 + 72a - 22a^2 - 225F_w}) & \text{if } a_1 \leq a < 1.5 \\ \text{but } l_1 > 0 \text{ only if } a > 1.09 \\ \frac{3}{50}(-8 + 16a - 3\sqrt{2}\sqrt{-27 + 33a - 8a^2 - 25F_w}) & \text{if } 1.5 \leq a \end{cases}$$

Both firms are capacity constrained

$$t = \begin{cases} \frac{1}{32}(-19 + 32a + \sqrt{425 - 1600F_w}) & \text{if } 1.5 \leq a, \\ \text{but } l_1, l_2 > 0 \text{ only if } a > 2.18 \end{cases}$$

The Lagrangean parameters, l_1 and l_2 , have to be positive if one or both firms are to be capacity constrained when subcontracting. So a price, calculated under the assumption that a firm was capacity constrained, has to be inserted into the functions of l_1 (and l_2) to endogenously check whether the firm actually is capacity constrained at the relevant demand region. In summary, the critical demand levels and the appropriate profit functions are

Demand	Profit without sub.	Profit with sub.
$0 \leq a < a_1 = 0.95$	$f_{no\ cc}$	$g_s\ no\ cc$
$a_1 \leq a < 1.09$	$k_{no\ cc}$	''
$1.09 \leq a < 1.5$	''	$g_s\ firm\ 1\ cc$
$1.5 \leq a < 2.18$	$k_{both\ firms\ cc}$	''
$2.18 \leq a$	''	$g_s\ both\ firms\ cc$

For demand region $0 \leq a < a_1$ firm 1 would not choose a price. It would prefer not to make any offer because its profit with subcontracting $g_s\ no\ cc$ would be lower than its profit without subcontracting $f_{no\ cc}$. Thus, the optimal subcontracting price t is

$$t = \begin{cases} no\ offer & if\ 0 \leq a < a_1 \\ \frac{a - \sqrt{a^2 - 9F_w}}{2} & if\ a_1 \leq a < 1.09 \\ \frac{3}{50}(-8 + 16a - \sqrt{2}\sqrt{-18 + 72a - 22a^2 - 225F_w}) & if\ 1.09 \leq a < 1.5 \\ \frac{3}{50}(-8 + 16a - 3\sqrt{2}\sqrt{-27 + 33a - 8a^2 - 25F_w}) & if\ 1.5 \leq a < 2.18 \end{cases}$$

The optimal subcontracting price is now inserted into the reduced form profit function of the appropriate capacity case. At demand levels $a_1 < a < 1.09$ this is the profit function $g_s\ no\ cc$ where no firm is capacity constrained, at demand levels $1.09 \leq a < 2.18$ it is the profit function $g_s\ firm\ 1\ cc$ where only firm 1 is capacity constrained.

Case (n_s, o_s)

Firm 1 produces product x in one plant and product y in one plant and firm 2 produces product y in one plant. In the third stage of the game firms determine the optimal quantities and the Lagrangean parameters by solving equations 4.3 and in the second stage of the game firm 1 chooses the optimal subcontracting price by solving equations 4.4.

No firm is capacity constrained: $(x_1, y_1, s, y_2) = (\frac{a+t}{3}, \frac{a}{3}, \frac{a-2t}{3}, \frac{a}{3})$

$$t = \begin{cases} \frac{a - \sqrt{-9 + 9a - a^2 - 9F_w}}{2} & if\ 1.5 \leq a < a_2 = 2.05 \\ but\ t < 0\ if\ a > 1.91 \end{cases}$$

Firm 1 is capacity only for product x:

$$(x_1, y_1, s, y_2, l_1) = (2 - a + t, \frac{a}{3}, a - 1 - t, \frac{a}{3}, 2a - 3 - t)$$

$$t = \begin{cases} a - 1 - \frac{\sqrt{-9+9a-a^2-9F_w}}{3} & \text{if } 1.5 \leq a < a_2 = 2.05 \\ \text{but } l_1 > 0 \text{ only if } a > 1.56 & \\ a - 1 - \frac{\sqrt{a^2-9F_n}}{3} & \text{if } a_2 \leq a \end{cases}$$

Both firms are capacity constrained only at demand levels $a \geq 3$.
Then optimal prices are

$$t = \begin{cases} \frac{a - \sqrt{-9+9a-a^2-9F_w}}{2} & \text{if } 1.5 \leq a < 1.56 \\ a - 1 - \frac{\sqrt{-9+9a-a^2-9F_w}}{3} & 1.56 \leq a < a_2 \\ a - 1 - \frac{\sqrt{a^2-9F_n}}{3} & \text{if } a_2 \leq a \end{cases}$$

Case (m_s, l_s)

Firm 1 produces product x in one plant and product y in a second plant and firm 2 produces products x and y in one plant. The demand region of particular interest is $1.56 \leq a < a_2$, where the in case (n_s, o_s) firm 1 with subcontracting would be capacity constrained. Here, for any positive subcontracting price, the case were only firm 2 is capacity constrained would apply:

$$(x_1, y_1, s, x_2, y_2, l_1) = \left(\frac{a+t}{3}, \frac{a+t}{3}, \frac{2a-3-4t}{3}, \frac{3-a+2t}{3}, \frac{a-2t}{3}, t \right) \text{ and}$$

$$t = \begin{cases} \frac{-9+8a+\sqrt{-207+144a}}{16} & \text{if } 1.5 \leq a < a_2 = 2.05, \text{ but } m_s < m \\ \frac{-9+8a-\sqrt{81-144a+64a^2-288F_n+288F_w}}{16} & \text{if } a_2 \leq a, \text{ now } m_s > m \end{cases}$$

The case where firm 1 is capacity constrained with product x and firm 2 is capacity constrained can only arise at demand levels $a > 2.19$. The case where both firms are capacity constrained with both products can only arise at demand levels $a > 2.23$. This means that the product-plant combination (m_s, l_s) leads to the same results as the combination (n_s, o_s). Firm 1 has no incentive to subcontract at demand levels at which consumer would have benefited from subcontracting.

Appendix C

Region	Firm 1	Firm 2	Exchange
3	x, y	x, y	$y_1 \geq \frac{e}{r}, x_2 \geq e$
6	x, y	y	$y_1 \geq \frac{e}{r}, x_2 = e$
2	x	x, y	$y_1 = \frac{e}{r}, x_2 \geq e$
5	x	y	$y_1 = \frac{e}{r}, x_2 = e$
8	x	y	$y_1 = \frac{e}{r}, x_2 \leq e$
4	x	y	$y_1 \leq \frac{e}{r}, x_2 = e$
7	x	y	$y_1 \leq \frac{e}{r}, x_2 \leq e$
9	x, y	y	$y_1 \geq \frac{e}{r}, x_2 \leq e$
1	x	x, y	$y_1 \leq \frac{e}{r}, x_2 \geq e$

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